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DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Institution's First Royal Patron

AT the Institution of Chemical Engineers Annual Dinner, Mr. John A. Oriel, president, announced that H.R.H. Prince Philip, Duke of Edinburgh, has become the Institution's first Royal Patron. This announcement, following upon the recent granting of a Royal Charter, ensures that 1957 will for ever be a landmark in the Institution's history.

Lord Chandos, who proposed the toast, paid tribute to the contribution of the chemical industry (and by inference the body of chemical engineers it employs) to the material wealth of the nation. Among the many achievements quoted by him was the production of sulphuric acid, a chemical without which the engineering industry could not function. He also pointed to the advances in petrochemicals and, here again, we must infer that he had in mind the large part that chemical engineers had played in developing the petrochemical industry. According to Lord Chandos, hardly any aspect of life was unaffected by the products of the chemical industry. One exception was the common cold. He concluded with an appeal to the education authorities to attract more people into the scientific courses, a direction in which he felt certain the Institution could play a leading part.

Mr. Oriel, the past president, replying to the toast of the Institution, described the recent granting of the Royal Charter as a landmark in the history of the Institution and, indeed, of chemical engineering. He felt that members could be justifiably proud of this honour. Before presenting the 1956 and 1957 Osborne Reynolds Medals to Dr. J. M. Pirie and Mr. P. K. Standring respectively, he handed over his seal of office to the incoming president, Sir Hugh Beaver.

Earlier, in his presidential address at the General Meeting of the Institution of Chemical Engineers, Mr. Oriel described how 35 years ago the petroleum refining industry found itself in need of large scale plant and since that time how industry had called for continuous chemical engineering efforts to supply its needs in the way of plant. He spoke of the great opportunities the cracking process had offered to chemical engineers. As an example, he told how it had released large quantities of unsaturated gases which were now the starting point for more than half the world's supply of organic chemicals. He brushed aside as unrealistic any idea that coal and oil should be used only as chemical raw materials and not as fuels. It was true that the world's reserves of oil were being rapidly depleted but he had every confidence that the members of his profession would be able to devise processes for making liquid fuels when the call for them arose.

Automation and Computation

PROPOSALS for the establishment of a British Conference on Automation and Computation are being considered by about twenty interested organisations, after exploratory discussions organised recently by the Institutions of Civil, Mechanical, and Electrical Engineers. The proposed Conference would be divided into three groups of societies having the following fields of interest: Group A—Engineering applications of automation techniques. Group B—Development and applications of computers, automatic controls and programming techniques. Group C—Sociological and economic aspects of automation and computation procedures. Of Group A the convener to be invited would be the Institution of Mechanical Engineers and the additional sponsors would be the Institutions of Civil, Chemical, Electrical, and Production Engineers.

Common Market and Chemicals

HOW will the proposals for the European Common Market affect British chemical engineering and chemical industries, is a question that must have been asked many times by British industrialists, particularly in view of growing European competition. To meet this kind of question the Westminster Chamber of Commerce has published a short report on the Common Market. Its particular aims are threefold—to present the plan simply; to assist readers to appreciate how it will affect them; and to summarise the varying reactions to it at home and abroad. The Chamber's task has been formidable if only on account of the highly technical nature of the 150-page report of the Messina conference, but the result is a publication of wide usefulness. Individual attitudes to the Free Trade Area proposals depend, the report points out, on individual estimates of the risks of staying out; the gains from joining in; and the losses from joining in. The British Government's provisional attitude towards the Messina scheme, the report says, is conditioned by its conviction that the world in the second half of the 20th century will be dominated economically by the U.S.A. and the U.S.S.R. unless the great reserves of economic strength at present scattered within Europe can be concentrated. The Dominions took the view that they were not prepared to lower their barriers against European manufacturers. The U.K. Government, therefore, proposes to reconcile European and Commonwealth interests by joining a European free trade area and abolishing by agreed stages all barriers between countries within the market, but retaining existing British tariffs against the rest of the world.

Among the views on the Free Trade Area proposals current in Britain which are quoted are those of Sir Graham Hayman, who points out guardedly that Western Europe is moving away from protection towards greater freedom of trade; the F.B.I. which has expressed qualified approval; and the British Labour Party, which has supported the Government's action in this matter. To these expressions of opinion may be added that of the National Union of Manufacturers, as stated in a letter sent to the President of the Board of Trade by Mr. C. S. Garland, the Union's president (and a past president of the Institution of Chemical Engineers). He asks for a declaration of

Government policy on industries liable to suffer from the effects of the proposals, and refers to the possible "total destruction" of a number of industries in Britain.

Copies of the Chamber's report, price 3s. 6d. each, are obtainable from Westminster Chamber of Commerce, Mitre House, 177 Regent Street, London, W.1.

Boron in the News

BORON being a good neutron absorber has received plenty of attention from the designers of nuclear reactors. Of the two varieties of Boron, B10 and B11, the former is much the better neutron absorber. Its main use to date has been as a material of construction for control rods. Now with greater availability due to the development of better processes for separating B10 from B11 there is a probability that its use may be extended in other directions, such as the shielding of reactors. Up to now, lead or concrete have been the main materials of construction for reactor shields, but B10, as an arrestor of neutrons, is twenty times more effective than lead and 500 times better than concrete. It therefore offers the possibility of lighter and more compact reactor shield structures. Lead or concrete would, however, still be necessary, as B10 has no effect upon gamma rays.

The American Hooker Electro-Chemical Company have developed a new distillation plant for the separation of B10 from B11. In their process natural Boron containing about 20% B10 is converted to a Boron-trifluoride dimethyl-ether complex. The B10 and B11 complexes are then separated—there are 360 transfer stages by fractional distillation—and in the process the B11 complex is the overhead product. Its relative volatility compared with the B10 complex is 1.015.

The process also involves the production of dimethyl-ether required for the preparation of the Boron complexes. This part of the process includes a vapour phase dehydration of methanol at temperatures approaching 400°C, and at pressures around 15 atmospheres employing alumino silicate catalyst. The electrolysis of potassium fluoborate prepared from B10 complex yields pure B10.

New Boron Compound

AS boron tribromide is expected to be of use in the case hardening of ferrous and non-ferrous metals (by boride formation at the surface) the availability of experimental quantities of the salt from British sources, recently announced by Borax Consolidated, is a development noteworthy to plant manufacturers. At present the salt is being made at the manufacturers' Research Laboratories at Chessington, Surrey. Many of the compound's reactions are similar to those of boron trichloride, and possible non-metallurgical applications include its use as a catalyst in the isomerisation of paraffin and olefin hydrocarbons or in polymerisation reactions for making synthetic rubber and high molecular-weight resins. The compound is also an effective brominating agent. It is a liquid at room temperature and is convenient to pack, transport and store.

Industry in Canada

IN 1956 a new record in the production of metals was reached in Canada; the total value of the products, $1134 million exceeded the previous year's figure by $126 million. As in 1955, the production of greatest value was copper, $291 million's worth of the metal being produced against $240 million's worth in the previous twelve months. The value of nickel production rose from $215 million in 1955 to $223 million in 1956 (details of International Nickel's activities are reviewed below), and only gold and lead fell below the level of the previous year. The value of iron ore produced rose to $156 million, but as output is expanding rapidly it is thought that within five years, this mineral should be, on present prices, a more important item than copper. In the meantime, uranium is expected to become the most important metal in terms of value, with production for 1958 estimated at about $350 million. Production in 1956 rose by $14 million to $40 million. The development of this metal has provided opportunities for the use of a specialised range of British equipment, and it is also giving a powerful stimulus to the local production of sulphuric acid and lime. The first Canadian production of uranium metal is planned for 1957, and A.M.F. Atomics of Canada Ltd. are building a plant at Port Hope for the fabrication of nuclear fuel elements. In oil refining construction, the emphasis is at present less on expansion of total capacity than on improvements to produce higher octane gasolines. Imperial Oil, however, plan to spend $17 million on enlarging their Calgary plant and British Petroleum have announced their intention of building a refinery in Montreal East of 30,000 barrels daily capacity. British Columbia, where oil was first produced in 1956, is expected to assume increasing importance as new oil resources are discovered along with the search for natural gas. The expansion of the Canadian oil industry has been accompanied by only comparatively limited sales by U.K. manufacturers of oil-field and refinery equipment. The increasing participation of U.K. capital in the industry may improve the prospects of British suppliers to some extent, but the predominantly American companies have, in the past, generally been open to offers of suitable supplies from the U.K. where price, delivery dates and servicing were competitive. Developments in nuclear power include the construction, now well under way, by the Ontario Hydro Electric Commission, the Canadian General Electric Co. Ltd., and Atomic Energy of Canada Ltd., jointly, of a 20,000 kw nuclear power station at a site on the Ottawa River. Atomic Energy of Canada also are designing a larger power reactor in the range of 100,000 kw to 200,000 kw, and they expect to spend about $110 million on this and other development over the next five years.

Record Year for Nickel

DURING 1956 International Nickel of Canada achieved new records in earnings and ore production, and launched a major project in Manitoba for the development of what is expected to become the world's second largest nickel mining operation. For the seventh successive year International Nickel's plant for producing primary metals were operated to the limit of capacity, and the ore mined amounted to 15,511,000 tons, compared with 14,248,000 tons in 1955. Deliveries of nickel in all forms in 1956 amounted to 286 million lb., and of copper 271 million lb. Other deliveries included 371,000 ounces of platinum metals (74,000 ounces less than in 1955) and, for the first time, pellets from the new iron ore recovery plant near Copper Cliff.

Construction was started of a new 6000-ton-a-day concentrator at Levack, and Canadian Industries commenced building a second plant at Copper Cliff for the production of sulphuric acid. The plant will utilise rich sulphur-dioxide bearing gas generated by the fluid-bed roasters of the new iron-ore recovery plant. In addition, an agreement has been made whereby Texas Gulf Sulphur will build and operate a pilot plant at Copper Cliff to investigate processes for the recovery of elemental sulphur. Plans for

1957 provide for putting the maximum number of men and machines to work on the company's Manitoba properties, so that by 1960 the new Thompson and Moak Lake mines and surface plants will be in production. Within 12 months after that date, i.e. 15 years after the company began exploration in Manitoba, these mines are expected to operate at planned capacity. Including the increases at their Sudbury plant, the company should then have an annual nickel production capacity of 385 million lb.

Farbenfabriken Bayer

FARBENFABRIKEN BAYER'S investment in 1956 totalled more than DM 230 million (£19,600,000), a slight increase on that of the previous year. Large sums were spent on increasing capacity in basic chemicals, and the Perlon-fibre installations at Dormagen have been extended. Work has continued on the Dralon-fibre plant which is expected to come into operation soon, and the titanium-white plant, being built at Uerdigen will probably be commissioned towards the end of this year. The increase in the company's turnover during the year was 11%, compared with 19% in 1955. Sales increased from DM.1,400 million (£120 million) to DM.1,600 million (£136 million), of which approximately DM.635 million (£54 million) was in respect of exports. Exports sales expanded more than home market sales during 1956. The company's labour force increased by 4.5% (to 48,826) and wages and salaries rose by about 15% to DM. 320 million (£27,200,000).

Texas Chemical Industry

EXPANSION in the chemical industry, particularly in ethylene production, on the Texas Gulf coast, an area in which about one-quarter of America's chemical plant development is concentrated, was described by G. H. Turrentine, general manager of Houston, Texas, Chamber of Commerce, in a special issue of the American *The Journal of Commerce* published to mark the recent holding of the 131st National Meeting of the American Chemical Society.

The new equipment includes an ethylene plant of Humble Oil & Refining Co. expected to go on stream in the middle of 1958 and having an initial capacity of 80 million lb. a year. It will obtain cracked gases from three cracking units one of them being a new cracker which is expected to be commissioned in February, 1958. The company also plans to build what is claimed to be the world's largest benzene production plant at Baytown. Its capacity, it is reported, will be 30 million gallons a year and the unit will go on stream in December, 1957. By January, 1958, the ethylene plant of Petroleum Chemicals will have a capacity of 200 million lb. a year. Petroleum Chemicals are also entering the liquid fertiliser field with the construction of a 100,000 ton anhydrous ammonia plant. The Calcasieu Chemical's petrochemical plant will be operated for its owners by P.C.I. and will produce about 8 million gallons a year of ethylene glycol. The intermediate, ethylene oxide, will go into other petrochemical compounds.

In 1956, Gulf Oil produced about 390 million lb. of ethylene, 376 million lb. being sold, and the remainder going into storage in its salt-dome cavern at Fannett, northwest of Port Arthur. Dow put on stream new plants to produce acetylene, methyl-acetylene, ethanolamines, synthetic glycerine and soil fumigants. It announced expansion of units to produce butadiene, chlorine, ethylene oxide, methyl chloroform, synthetic glycerine, glycols, magnesium, perchlorethylene and styrene. Rohm & Haas are building new plant to produce ammonia, methanol, oxygen and acetylene. Their neighbours, Diamond Alkali, are to increase their production capacity of electrolytic products (chlorine and caustic soda) by 40% and of perchlorethylene by 100%. They are also building a unit to produce acetylene. Shell Chemicals, late in 1956, completed two units which tripled their production of Epon resins, and they are building a unit to produce 20 million lb. a year of isopropyl alcohol. Jefferson announced during 1956 that it will triple its production of ethylene, double its capacity for ethylene glycol, and increase ethylene oxide capacity by 50%. They will also build a plant to produce chlorine for use in manufacturing ethylene oxide and ethylene dichloride. Production of synthetic rubber from enlarged plants planned during 1955 and 1956 following transfer of the equipment from Government to private ownership is now coming on stream in the Gulf area.

Petrochemicals in Puerto Rico

In Puerto Rico recently there has also been a notable expansion in the petrochemicals industry, two big oil refineries and one $12-million fertiliser plant, for example, having been erected during the past 18 months. The latest developments include the commissioning this year of a $12½ million ammonium sulphate plant by Gonzalez Chemical Industries. This plant, which is said to be almost completely automatic, produces anhydrous ammonia and sulphuric acid, and then combines the two compounds to produce ammonium sulphate at the rate of 120,000 tons a year. Its sulphuric acid capacity exceeds 115,000 tons a year. Plant for which plans have been announced include a $285 million ethylene-glycol plant for East Union Carbide in Guayanilla. Commonwealth Oil is adding $15-20 million's worth of new plant designed to supply raw ethylene, ethane, methane, hydrogen, propane, and propylene to the proposed Union Carbide plant. It has been estimated that during the past two years $100 million of American capital has been invested in the petrochemicals industry in Puerto Rico. That support has been stimulated by the operation of "Operation Bootstrap," a tax-free industrialisation scheme aimed at building up the country's economy.

Factory Efficiency and Safety

A SPECIAL feature of the fourth Safety and Factory Efficiency Exhibition to be held by the Birmingham and District Industrial Safety Group in Birmingham during the period June 14-21 will be a large display staged by the U.K. Atomic Energy Authority. Occupying about 4000-5000 sq. ft. it will illustrate the uses and potential applications of nuclear energy and of isotopes in industry, and the precautions to be taken for the protection of staff and the public against radiation hazards. A congress, which has been planned to assist industrialists, engineers and other technologists on the industrial aspects of atomic energy, will be held simultaneously with the exhibition. Chairman of the congress will be Dr. P. F. R. Venables, principal of Birmingham College of Technology. Speakers will include Mr. Ivor Hopkins, chief training officer, Industrial Group, U.K.A.E.A.; Dr. W. J. Arroll, research manager, Joseph Lucas (Electrical) Ltd.; Dr. H. Seligman, head, Isotope Division, A.E.R.E., Dr. A. S. McLean, chief medical officer, Industrial Group, U.K.A.E.A., Professor M. Stacey, Birmingham University, and Dr. J. V. Dunworth, C.B.E., head, Reactor Division, A.E.R.E.

New Australian Sulphur Burner

READERS who have followed closely the recent series of papers by Lowrison and others (see page 318), published in recent issues of our journal, on the production of sulphur dioxide from sulphur containing materials will be interested in the appearance of a new burner for treating sulphur ores. This new burner has been designed to treat high sulphur ores (95% sulphur containing bitumen). The basic feature of this new burner, the work of the Commonwealth Fertiliser and Chemical Co. Ltd., of Melbourne, is the use of a fluid-bed of hot sand. The sand is rendered fluid by means of air which also burns some of the sulphur to the dioxide. The remaining sulphur is volatilised and is subsequently burned to the dioxide in a separate combustion chamber adjacent to the fluidising vessel. The unit has a 30 ton output and includes a 4 ft. diameter fluid-bed vessel and an 18 ft. diameter combustion chamber. The unit is very flexible and it will respond rapidly to changes in SO_2 demand. It therefore avoids the necessity of keeping a bath of molten sulphur burning should the SO_2 demand suddenly cease.

Plant and its Control

AN intensive two-day course on chemical and engineering problems in industrial processes, held recently at the College of Technology, Bristol, was attended by technologists from many parts of the country. Dr. K. W. J. Bowen, of I.C.I. metals division, speaking on titanium as a material of construction, forecast that the price of fabrication of titanium into sheet, rod, tube and wire, though high now, would be reduced by a half by 1961. Castings of the metal would be available in the near future. The present use of titanium was closely restricted to those problems where its use was justified. Its resistance to corrosion (due to a protective oxide film), particularly when in contact with chloride- and sulphide-containing liquid and its smaller density made the metal particularly valuable for chemical engineering applications. Its main use at present was for linings in reaction vessels, pipes, trunkings, nozzles of injectors.

Dr. A. J. Young, president of the Society of Instrument Technology, said the application of automatic process control in the chemical industry was based on the economics of problems. To obtain the full advantage that the system offered, an industrial designer must be aware of the basic principles of control systems and of the influence of the characteristics of the plant on performance. Trial and error was no longer desirable. The analysis of results by frequency response and other methods was enabling improvements in efficiency of new plants to be made at the drawing-board stage and was allowing checks to be made on the theoretical predictions. Interlink systems should be examined so that the accuracy of measurement could be improved beyond the existing limit of about 1%. The advent of the electronic computer would help to solve many problems connected with the analysis and evaluation of the characteristics of plants and operating conditions, and it might lead eventually to the linking together of all important measurements under one master plant controller.

Clean Air Council

THE twenty-nine members of the Clean Air Council recently appointed by the Minister of Housing and Local Government, Mr. Henry Brooke, represent a wide range of interests, including private and nationalised industry, science and technology, medicine, transport, local authorities, trade unions, and women advisors on solid fuel.

The Minister, as chairman, will have the assistance of Mr. Bevins, Parliamentary Secretary to the Ministry of Housing and Local Government, and Mr. David Renton, Parliamentary Secretary to the Ministry of Power as vice-chairmen. The other members include Sir Hugh Beaver, chairman, Arthur Guinness and Co. Ltd.; Commander C. Buist, chairman, Low Temperature Coal Distillers Association, vice-president, National Union of Manufacturers; Mr. J. A. Connel, director Technical Division, Unilever Ltd.; Sir Josiah Eccles, deputy chairman, C.E.A.; Mr. C. S. Garland, president, National Union of Manufacturers; Lt.-Col. Lord Dudley Gordon, member of Council and Executive Committee, British Iron and Steel Federation; Mr. R. W. Husband, controller of Engineering Department, Beecham Group Ltd.; Sir Henry Jones, deputy chairman, Gas Council; Mr. J. Latham, deputy chairman, National Coal Board; Dr. W. A. Macfarlane, Chief Executive, National Industrial Fuel Efficiency Service; Dr. Ll. Roberts, M.O.H., Sheffield; Dr. S. W. Saunders, managing director, Billingham Division, I.C.I.; Prof. A. B. Semple, M.O.H., Liverpool; Prof. M. W. Thring, Professor of Fuel Technology and Chemical Engineering, University of Sheffield; Mr. C. M. Vignoles, general manager, Shell-Mex and B.P. Ltd.; Mr. A. H. Wilson, F.R.S., managing director in charge of research and development, Courtaulds Ltd., member of the Fuel Research Board, D.S.I.R.

Under the provisions of the Clean Air Act, 1956, and an Order dated May 8, 1957, the Minister is empowered to appoint the Council as a consultative body to assist him in keeping under review the progress made in dealing with pollution of the air in England and Wales; and in obtaining the advice of persons having special knowledge, experience or responsibility in the prevention of air pollution. Thirty members can be appointed, and they hold office for terms of three years.

Technical College Libraries

AS part of the Government's drive to expand technical education, the Minister of Education, Lord Hailsham, has recommended to local education authorities that qualified librarians should be appointed "early" to the larger technical colleges. In his circular letter on the subject the Minister points out that the maintenance of an adequate library service is comparatively expensive, but the service is essential if students are to be trained to seek up-to-date information, to become independent workers rather than passive recipients of lecture notes, and to keep pace with scientific developments after they have passed their examinations. He advises that from £500 to £2000, according to the size of college, should be set aside as an annual allowance for the purchase of books and periodicals. A minimum of 3000 volumes should be the stock target, but periodicals may be more important even than books especially to advanced students in technologies which are developing rapidly. To encourage their use, libraries should be easily accessible. Separate reading rooms for books and periodicals may be desirable, while it is suggested that in a college doing much advanced work, a small separate room may be required for reading micro-texts. The circular calls for imaginative publicity, both inside and outside the library, to help attract part-time students, especially evening students, who frequently fail to realise that the library is an integral part of the college.

Although the Minister is to be supported in the recommendations he has made, their implementation must not be allowed to obscure the fact that the primary need in technical education is for more colleges of the right kind and more teachers.

BRITISH CHEMICAL ENGINEERING
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Problems of Education

THE recent symposium on chemical engineering education (see pages 316-317) may be looked upon as a good introduction to this complex problem. Several new ideas on subjects to be taught and on teaching methods came to light, but their effectiveness in terms of the chemical engineer they produce will have to be proved. That the symposium was timely and necessary was demonstrated by the size and character of the attendance. Industry and the higher-education establishments were equally represented and there was a fair sprinkling of school teachers. A feature of the symposium was the clarity with which the teaching side, recognising the speed with which the technology is developing, expounded their theories and described the courses that they had devised.

From the initial discussion of the requirements of industry, the conference developed logically to its other main themes—methods of training; new trends; and recruitment to the profession. It was evident from the ideas advanced in the first session that the kind of chemical engineer sought by industry is a good all-rounder technically and, moreover, one who has a capacity for leadership. Industry came in for some criticism for expecting the newly-qualified chemical engineer to be cost-conscious to a high degree, when, indeed, industry itself is the jealous custodian of the essential facts which would enable him to act as the co-ordinator of a project and manipulate its economics.

Refreshing views on trends in the teaching of chemical engineering were presented in the third session. Professor Sellers urged the greater use of mathematics in chemical engineering, and it was recommended that the teaching of the subject be continuous and always related to actual problems. We agree with him when he says that it is important to break down the student's resentment that in his first year he is devoting what seems to him a disproportionate part of his time to pure mathematics. However, we feel that the Universities' task would be made easier if a similar method of teaching mathematics was adopted at the school stage. Professor K. G. Denbigh made a case for the generous provision of thermodynamics, although, wisely, he warned against an excess of the subject.

The growth of a chemical engineering science was one of the important developments which the conference threw into relief. The dangers of too much concentration on this new science was stressed and several speakers advocated its tempering with common sense and experience. We feel that there is a great risk of this new offshoot becoming separated from the main body, which would result in the production of an engineer competent in theory but inadequate practically and devoid of a sense of urgency. Nevertheless, this new science has its place in advancing the frontiers of chemical engineering.

Industry, we feel, can assist in the production of the chemical engineers that it requires by offering the student an opportunity of gaining first-hand experience of chemical plant under industrial conditions. Chemical engineering education is, in fact, a partnership between industry and the teaching institutions, and it was encouraging to note that the existence of this relationship was widely acknowledged at the conference. Even so, it is not as generally adopted as it should be. A unique development in industry-university relationship was described by Dr. F. Rumford, who is pioneering a works study scheme in the Glasgow area in which students work on actual industrial problems, acting, as it were, as unpaid consultants at a "host" plant. The principal difficulty with this scheme, so far as the university is concerned, has been merely one of finance. Here again, we feel, industry can advance its own interests by ensuring that the growth of such schemes will not be stunted for lack of funds.

How the qualified engineer can keep abreast of developments is another important problem and is one which merits more attention. Industry could provide greater assistance by ensuring that the engineer is given adequate facilities for attending meetings, and by otherwise maintaining his scientific contacts. The chemical engineer in industry is confronted with advances in knowledge and changes in approach which require of him continual readjustment and assimilation of new techniques and procedures. Even although he may be fully occupied with administrative commitments, no genuine engineer will voluntarily turn his back on progress and resign himself to stagnation. This applies particularly to the chemical engineer in the smaller firm, who has no recourse to extensive research and development departments to solve his problems. Moreover, it cannot be argued that the complexity of problems with which a firm is confronted is related to its size. A suggestion has been made for private study, but this alone is inadequate and impracticable.

A recurring theme in the symposium was the inadequacy of the chemical engineer to express ideas. Since chemical engineers are often at the centre of a heterogeneous team of scientists and technologists, the importance of being able to communicate clearly at various levels cannot be overemphasised. The criticism was raised that this shortcoming is the chemical engineers' greatest weakness. However, they are not alone in this deficiency. In remedying the fault, consideration might well be given to adopting more widely courses like the one described by Professor M. B. Donald on the presentation of technical information, now included in the training of chemical engineers at University College, London. From his paper, it appears that his students do not lack knowledge of English. This suggests to us that cause of the fault should possibly be sought in other directions—perhaps in unfamiliarity with logic. Nevertheless, this should in no way diminish the value of the recommendation made by the Master of Dulwich College (himself a chemist) that boys specialising in science should be taught English by the ablest teachers who could "appeal to the poet in all of them, giving them a love and appreciation of good writing".

To sum up, the symposium certainly formed a useful forum for the exchange of ideas on the subject of chemical engineering education. Too long a time should not be allowed to elapse before a further symposium is held to assess the value of the various courses and to decide what should be retained, what added and what discarded. Moreover, this would be an opportune time to discuss the problems confronting the qualified engineer in greater detail.

FOG FORMATION AND THE DESIGN OF COOLER-CONDENSERS AND COOLER-ABSORBERS

Although methods for the design of cooler-condensers have been developed by Colburn and Hougen[1], Bras[2] and Cairns[3], no attention has been given to the similar problem of cooler-absorbers. In this article the design of both kinds is described

by C. G. GARDNER, B.Sc., A.C.G.I.

SYMBOLS USED

a = defined by Equation (9);
$f(a)$ = defined by Equation (8);
dA = differential cooling surface area (ft²);
c_p = specific heat (CHU/lb. °C);
D = diffusivity of vapour in inert gas (ft²/hr);
G = gas mass flow rate (lb./hr);
h_G = gas film sensible heat-transfer coefficient (CHU/hr ft² °C);
dH = differential sensible heat-transfer rate (CHU/hr);
k = gas conductivity (CHU/ft hr °C);
k_G = gas film mass-transfer coefficient (lb. mole/hr ft² atm.);
M = molecular weight;
dN = differential mass-transfer rate (lb. mole/hr);
p = partial pressure (atm.);
$p_{BM} = \frac{(P-p_G)-(P-p_s)}{ln\left(\frac{P-p_G}{P-p_s}\right)}$ Barometric mean pressure (atm.);
P = total pressure (atm.);
R = gas constant;
T = absolute temperature (°K);
x = perpendicular distance from interface into gas stream (ft);
$f_D(x)$ = function of x in Equation (17);
$f_H(x)$ = function of n in Equation (16);

$Pr = \frac{c_p\mu}{k}$ Prandtl group;

$Sc = \frac{\mu}{\rho D}$ Schmidt group;

λ = latent heat of vaporisation (CHU/lb. mole);
ρ = gas density (lb./ft³); and
μ = gas viscosity (lb./ft hr).

Subscripts

c_p, k, M, ρ, μ, with no further subscripts, refer to the gas mixture;
d = dew-point;
G = gas, bulk of gas if symbol x is not present;
i = inlet gas;
I = inert gas;
o = outlet gas;
s = interface between liquid and gas;
v = vapour; and
x = position in boundary layer.

THE direct approach to the problem of the recovery of volatile material from an inert hot-gas stream and the solution which involves the least capital expenditure is to install a cooler-condenser. However, circumstances can arise when it may be advisable to exploit the advantages offered by a cooler-absorber, in which the cold condensation surface is replaced by a cold absorbing liquid-surface. The possible advantages of the cooler-absorber as compared with the cooler-condenser depend chiefly on the depression of the vapour pressure of the volatile material over the cooling surface at a given temperature, caused by the use of a solvent. Hence:

(1) The cooler-absorber will have a greater recovery efficiency.

(2) The rate of condensation or absorption is diffusion controlled, due to the presence of the inert gas, and the cooler-absorber will therefore have a greater rate of recovery per unit surface area.

(3) The tendency to super-cool the vapour in the gas stream, and therefore to form fog, becomes greater as the ratio of the sensible heat to mass-transfer rates increases. Because the rate of heat transfer, for a given surface temperature, is the same for both types of equipment, the cooler-absorber will have a smaller liability to form fog (see Fig. 1).

Further advantages may accrue in special cases. For instance, the vapour may be the product of a high-temperature reaction and may revert to the feed materials of the reaction unless the gas is quench-cooled. Under these circumstances, large volumes of cold liquid will effect the quenching very rapidly and the absorption technique may be employed, rather than the recirculation of cold condensate, for the tendency to fog formation is probably great.

The disadvantages of the cooler-absorber include the need for extra equipment to recover the volatile material from the solvent, the extra process costs and the need for replacing solvent losses. The recovery can be effected in two ways:

(1) The volatile material can be evaporated from the absorbent and recondensed. A heat exchanger will be required to cool the stripped absorbent before returning it to the cooler-absorber.

(2) A solvent can be chosen, in which the liquid volatile-material has a limited solubility. Cooling will then produce two liquid phases, which can be decanted from

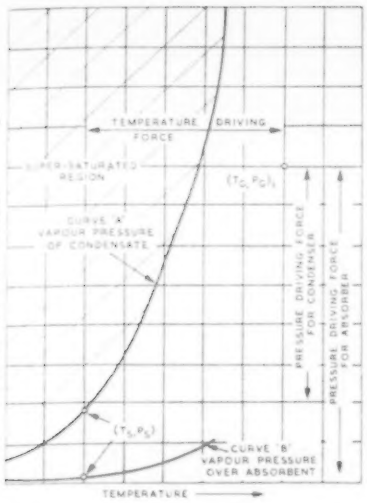

Fig. 1. Driving forces for a cooler-condenser and a cooler-absorber.

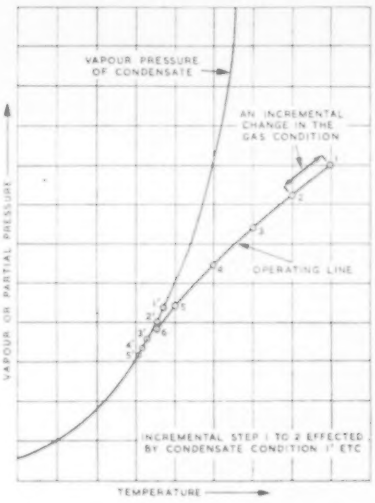
VAPOUR PRESSURE OF CONDENSATE
AN INCREMENTAL CHANGE IN THE GAS CONDITION
OPERATING LINE
INCREMENTAL STEP 1 TO 2 EFFECTED BY CONDENSATE CONDITION 1' ETC
TEMPERATURE

Fig. 2. Stepwise calculation procedure for a cooler-condenser.

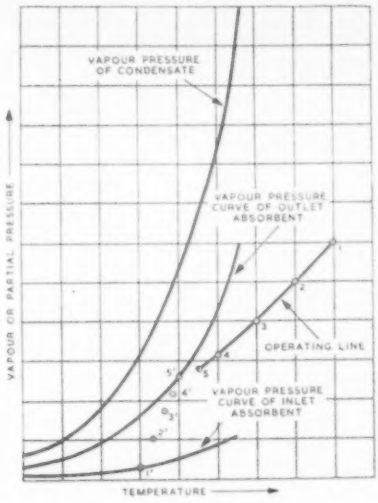

Fig. 3. Concurrent flow cooler-absorber.

one another. The absorbent may have to be reheated before returning it to the cooler-condenser, but this is not always necessary.

Design of the Equipment

Bras[2] and Cairns[3] recently discussed the design of cooler-condensers in detail. The approach of Bras, which derives from Colburn,[5] will be described here, for it is theoretically sounder and is not difficult to apply.

It will be assumed that the inlet condition—i.e., the temperature T_{Gi} and the vapour partial pressure p_{Gi}—of the gas stream to the cooler-condenser or cooler-absorber is known. The condition is plotted as point $(T_G, p_G)_i$ in Fig.1 and, as the gas is unsaturated, the point will lie to the right of curve A, of the vapour pressure of the pure volatile liquid with respect to temperature. Now imagine the gas to be cooled by a surface, on which some of the vapour condenses. The vapour at the condensate interface must be in equilibrium with the condensate and will be represented by an as yet undetermined point (T_s, p_s), lying on curve A. The differences $(T_{Gi} - T_s)$ *and* $(p_{Gi} - p_s)$ will be the driving forces for sensible heat-transfer and mass-transfer respectively. A similar situation occurs for the cooler-absorber, but in this case the point (T_s, p_s) will lie on curve B showing the vapour pressure over a solution of the volatile material in the absorbent.

As the gas stream moves through the equipment, its condition (T_G, p_G) will tend to move from $(T_G, p_G)_i$ to (T_s, p_s), along what is called the operating line, in order to obtain equilibrium with the condensate or absorbent. However, to complicate matters, the equilibrium point (T_s, p_s) will, in general, continually shift its position, as heat and volatile material are extracted from the gas, so that the operating line will not have a constant objective.

The design procedure first calls for a definition of the equilibrium point (T_s, p_s) for a given gas condition (T_G, p_G), then for a calculation of the slope of the operating line at (T_G, p_G) and finally for a calculation of either heat-transfer rate or mass-transfer rate. Fig. 2 shows how such information is applied to a cooler-condenser. Suppose point 1 is the gas inlet condition and 1′ is the equilibrium condition associated with it. A line, with the slope of the operating line, is drawn through point 1 to run a short distance in the general direction of point 1′. It will represent with little error the change in the gas condition for a small section of the cooler-condenser at the gas inlet. The cooling surface-area required to effect this incremental change is calculated using, say, the change in temperature of the gas and the sensible heat-transfer coefficient. Now at point 2, the equilibrium condition will have changed to point 2′, which will be sufficiently different from 1′ to require recalculation of the slope of the operating line and the driving force $(T_G - T_s)$. In addition, as the operating line may be a curve, the use of a straight line to represent it may not be sufficiently accurate beyond point 2. Thus the process is repeated, through points 3, 4, and so on, until the desired gas outlet condition is achieved. In the meantime, the cooling surface-area requirements will have been calculated, and detailed information about the gas stream and the cooling surface throughout the equipment will have been obtained.

Slope of Operating Line

The manner in which the slope of the operating line is calculated is common to all types of equipment and will be dealt with first. The way in which the equilibrium point (T_s, p_s) is estimated varies with the specific problem and will be described afterwards.

The derivation of an equation for the slope of the operating line will follow in principle the method of Bras,[2] though the reader should find the present development simpler. For a differential area, dA, equations are writen for the differential sensible heat, dH, and mass, dN, transfers.

$$dH = h_G (T_G - T_s)\, dA = -G\, c_p\, dT_G \qquad \ldots.(1)$$

$$dN = k_G (p_G - p_s)\, dA = -\frac{G}{M} \frac{dp_G}{(P - p_G)} \qquad \ldots.(2)$$

The right-hand side of Equation (2) follows from writing the moles of volatile material present as

$$\frac{G}{M}\frac{p_G}{P} = \frac{G_I}{M_I}\frac{p_G}{(P - p_G)}$$

and, differentiating the right-hand side, G and M refer to the total gas stream, whereas G_I and M_I refer to the inert gas only.

Divide Equation (1) by Equation (2):

$$\frac{h_G}{k_G}\left(\frac{T_G - T_s}{p_G - p_s}\right) = c_p\, M\, (P - p_G)\frac{dT_G}{dp_G} \qquad \ldots.(3)$$

Now from the Chilton and Colburn[4] analogy between heat and mass transfer (by putting the j factors equal to

one another):

$$\frac{h_G}{k_G} = p_{BM}\, c_p\, M \left(\frac{S_c}{P_r}\right)^{\frac{2}{3}} \qquad \ldots.(4)$$

Substitute (4) in (3):

$$\frac{dT_G}{dp_G} = \left(\frac{p_{BM}}{P-p_G}\right)\left(\frac{S_c}{P_r}\right)^{\frac{2}{3}}\left(\frac{T_G-T_s}{p_G-p_s}\right) \qquad \ldots.(5)$$

Equation (5) is used to calculate the slope of the operating line $\frac{dT_G}{dp_G}$ at the point (T_G, p_G), when the point (T_s, p_s) is known.

Equation (5) can often be simplified, for, when p_G or $(p_G - p_s)$ is small compared with the total pressure P, the item $p_{BM}/(P-p_G)$ can be put equal to unity with little error.

If one is also fortunate and the equilibrium point (T_s, p_s) does not vary throughout the equipment, Equation (5) may be integrated to give the form of the operating line:

$$\left(\frac{p_G-p_s}{p_{Gi}-p_s}\right) = \left(\frac{T_G-T_s}{T_{Gi}-T_s}\right)^{\left(\frac{P_r}{S_c}\right)^{\frac{2}{3}}} \qquad \ldots.(6)$$

Thus, with reference to a fixed point (T_s, p_s), the operating line will be the straight line joining points (T_G, p_G) and (T_s, p_s), if the ratio $\left(\frac{P_r}{S_c}\right)$, which defines the balance between sensible heat and mass transfer, equals unity. Also, if the diffusion coefficient is decreased in value, so that the Schmidt number (Sc) becomes larger, the operating line will curve more to the left, towards curve A of Fig. 1, and towards the super-saturated and fog-forming region.

(T_s, p_s) and Surface Area for Cooler-absorbers

The variation of the equilibrium point (T_s, p_s) and the surface area requirements are much easier to calculate for cooler-absorbers than for cooler-condensers, since the heat is extracted in the absorbent stream and does not have to be transferred through a condensate film and metal wall to a cooling fluid.

The simplest case is that where point (T_s, p_s) is constant. This will occur when the volume of absorbent is so large that there is no appreciable change in either its temperature or the concentration of volatile material in it as it passes through the equipment. Then, if there is no great change in the gas mass flow-rate, G, Equation (1) can be integrated using average values of G and C_p, to give:

$$A = \frac{(G\ c_p)_{av}}{h_G}\, ln\left(\frac{T_{Gi}-T_s}{T_{GO}-T_s}\right) \qquad \ldots.(7)$$

where T_{GO} is the desired gas outlet temperature. p_{GO} will be calculated from Equation (6).

However, if the gass-mass flow G shows appreciable change over the whole cooler-absorber, a stepwise procedure must be used. In such a case, it is possible that $p_{BM}/(P-p_G)$ will not be equal to unity or constant, and thus steps must be chosen of small enough size so that Equation (5) and an average value of Gc_p can be used, without introducing substantial error. Equation (7) will be used to calculate the surface area required for each step, and an operating line will be built up, in the manner shown in Fig. 3, but with (T_s, p_s) held constant.

It is similarly easy to calculate the surface area required for a cooler-absorber with concurrent flow of gas and absorbent, and the process is shown in Fig. 3. At the end of each step, a new temperature—taking into account both the sensible heat transfer and the latent heat of vapour absorption—and a new concentration of volatile material in the absorbent are calculated, and they are used to define the new condition (T_s, p_s).

With a cooler-absorber in which the gas and absorbent flow are countercurrent the calculation is more difficult. It will be assumed that the condition $(T_s, p_s)_O$, at which the absorbent enters the cooler-absorber, is known and will be associated with a partial pressure of the vapour p_{GO}, which it is desired to attain. The inlet condition of the gas $(T_G, p_G)_i$ will also be known. By plotting these values on Fig. 4, a guess can be made as to the value of T_{GO} and, by considering the change in temperature and partial pressure of the gas, an approximation to condition $(T_s, p_s)_i$, of the absorbent leaving the cooler-absorber, can be obtained. Then the same procedure is used as for concurrent flow starting from the gas inlet conditions, except, of course, heat and mass transferred will have to be subtracted from the absorbent for each stage. Using this first approximation, the desired vapour partial pressure p_{GO} and the absorbent inlet condition $(T_s, p_s)_O$ will not be reached, but, from the experience gained, an adjustment can be made to T_{si}, and consequently to p_{si}, such that p_{GO} and $(T_s, p_s)_O$ will be attained simultaneously at a second attempt.

(T_s, p_s) and Surface Area for Cooler-condensers

Cooler-condensers also have been considered by Bras[2] and Cairns.[3] The stepwise procedures already described are applicable, but there is the additional camplication that the heat-transfer resistances through the condensate film, through the cooling tube wall, through scale and from the tube wall to the cooling fluid have to be considered. They can normally be summed to give an average overall condensate-gas interface to cooling fluid resistance r, which can be used throughout the equipment.

Equilibrium point (T_s, p_s) for a given incremental step must be found by trial and error. A value is chosen from the vapour pressure curve for the pure volatile liquid, as shown in Fig. 2, and the corresponding incremental step for the gas stream is drawn in, using the slope of the operating line from Equation (5).

The incremental gas temperature change $\triangle T_G$ will represent sensible heat and the incremental partial pressure change $\triangle p_G$ will represent latent heat, which have to be transferred together from the condensate-gas interface to the cooling fluid against the resistance r with a temperature difference $(T_s - T_c)$. T_c is the cooling fluid temperature. If the temperature difference $(T_s - T_c)$ is too large or too small to exchange the heat involved, equilibrium point (T_s, p_s) must be rechosen. Normally, with practice, the second choice is sufficiently accurate and, of course, experience is gained from the previous incremental step. It should be clear, from the previous discussion of the cooler-absorber, how the surface area of the cooler-condenser can be calculated.

Transfer of Sensible Heat by Diffusing Vapour

The sensible heat transferred by the diffusing vapour has been ignored in all the equations developed, but it can be an appreciable factor if the condensation rate is large. Due allowance can be made, as shown by Colburn and Drew,[6] by using:

$$f(a) = \left(\frac{1-e^{-a}}{a}\right) \qquad \ldots.(8)$$

where

$$a = \left(\frac{Pr}{Sc}\right)^{\frac{2}{3}} \frac{M_v\, c_{pv}}{M\, c_p}\, ln\left(\frac{P-p_s}{P-p_G}\right) \qquad \ldots.(9)$$

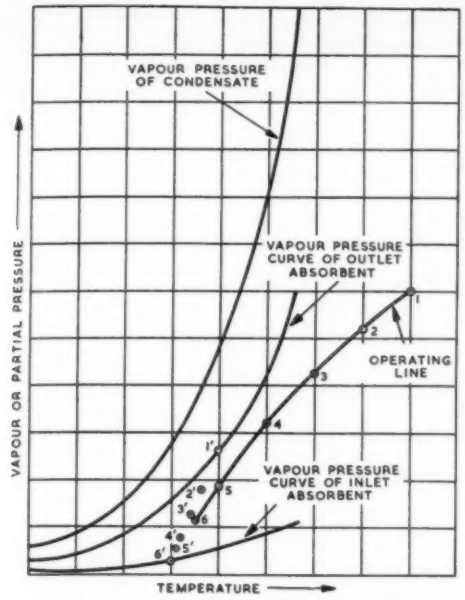

Fig. 4. Counter-current flow cooler-absorber.

Thus Equations (1), (5) and (7) become respectively:

$$dH = h_G\,(T_G - T_s)\,dA = -G\,c_p\,f(a)\,dT_G \quad \ldots.(10)$$

$$\frac{dT_G}{dp_G} = \frac{1}{f(a)}\left(\frac{p_{BM}}{P-p_G}\right)\left(\frac{Sc}{Pr}\right)^{\frac{2}{3}}\left(\frac{T_G-T_s}{p_G-p_s}\right) \quad \ldots.(11)$$

$$\triangle A = \frac{(G\,c_p f(a))_{av}}{h_G}\,ln\left(\frac{T_{G_1}-T_s}{T_{G_2}-T_s}\right) \quad \ldots.(12)$$

If it is necessary to employ $f(a)$, Equation (12) can only be used for an incremental area $\triangle A$ and from gas bulk condition 1 to condition 2.

Fog Formation

The problem of fog formation is one which must often be guarded against in designing cooler-condensers and cooler-absorbers. It is not, of course, sufficient to ensure that the bulk gas condition does not pass into a supersaturated region; there is also the boundary layer of gas between the bulk of the gas and the liquid gas interface to consider where, although the partial pressure of the vapour is reduced, the temperature is also decreased. Johnstone, Kelley and McKinley[7] have shown, rather elegantly, that the first appearance of fog in a cooler-condenser is always a boundary-layer phenomenon.

Fig. 5(a) represents desirable conditions in the boundary layer, where x is the distance measured from the interface. T_{G_x} and p_{G_x} will vary in a similar manner with respect to x from T_s and p_s to T_G and p_G respectively. A curve is also drawn for the dew-point temperature of the gas T_{dx} and, since the vapour at the interface is in equilibrium with its condensate, $T_{ds} = T_s$. It is apparent from Fig. 5(a) that fog will first tend to form at the interface ($x = 0$) and when the slope of the dew-point curve is equal to that of the gas temperature curve. That is, fog is liable to form when:

$$\left(\frac{dT_{dx}}{dx}\right)_{x=o} \geqslant \left(\frac{dT_{Gx}}{dx}\right)_{x=o} \quad \ldots.(13)$$

as shown in Fig., 5 (b) and (c).

A different situation arises from the cooler-absorber, for, at the interface $T_{ds} < T_s$ (see Fig. 6 (a)). It is apparent that fog will first be liable to form either at some indeterminate point in the boundary or in the bulk of the gas, where both the gas and the dew-point temperatures, and the slopes of the curves of these temperatures are equal, but never at the interface. Fog, therefore, is liable to form when:

$$\left(\frac{dT_{dx}}{dx}\right)_{T_{dx}=T_{Gx}} > \left(\frac{dT_{Gx}}{dx}\right)_{T_{dx}=T_{Gx}} \quad \ldots.(14)$$

Johnstone and colleagues found an analytical solution to the problem postulated by Equation (13) and proved it by observations in laboratory experiments. A graphical solution will be found for the more general case of Equation (14), since an analytical solution would be too unwieldy to use.

The heat being transferred at any distance x over a unit area of the boundary layer is $\frac{h_G}{f(a)}(T_G - T_s)$ and thus if the boundary layer were stagnant

$$\frac{dT_{Gx}}{dx} = \frac{1}{f(a)}\left(\frac{h_G}{k}\right)(T_G - T_s) \quad \ldots.(15)$$

However, turbulence occurs and increases with intensity with the distance x from the interface. Equation (15) will only be true at the interface itself. Therefore, the conductivity k will be replaced by a pseudo-conductivity $k/\left(\frac{df_H(x)}{dx}\right)$, where $f_H(x)$ is chosen such that the pseudo-conductivity equals k at $x = 0$. Hence $\left(\frac{df_H(x)}{dx}\right)_{x=0} = 1$ and $(f_H(x))_{x=0} = 0$

$$\frac{dT_{Gx}}{dx} = \frac{1}{f(a)}\left(\frac{h_G}{k}\right)(T_G - T_s)\frac{df_H(x)}{dx}$$

Integrate

$$(T_{Gx} - T_s) = \frac{1}{f(a)}\left(\frac{h_G}{k}\right)(T_G - T_s)\,f_H{}'x) \quad \ldots.(16)$$

Similar equations are written for mass transfer:

$$\frac{dp_{Gx}}{dx} = \frac{k_G\,RT_{Gx}\,p_{BM}}{DP}(p_G - p_s)\frac{df_D(x)}{dx}$$

$$(p_{Gx} - p_s) = \frac{k_G\,RT_{Gx}\,p_{BM}}{DP}(p_G - p_s)\,f_D(x) \quad \ldots.(17)$$

where $\frac{DP}{RT_{Gx}\,p_{BM}}$ is analogous to k (Sherwood and Pigford[1]) and $f_D(x)$ is a function of x different to $f_H(x)$, but with the same properties at $x = 0$.

Divide Equation (16) by Equation (17)

$$\left(\frac{T_{Gx}-T_s}{p_{Gx}-p_s}\right) = \frac{1}{f(a)}\left(\frac{h_G}{k_G}\right)\left(\frac{DP}{k\,RT_{Gx}\,p_{BM}}\right)\left(\frac{T_G-T_s}{p_G-p_s}\right)\frac{f_H(x)}{f_D(x)} \quad \ldots.(18)$$

Now from the Chilton and Colburn analogy, expressed by Equation (4), and the gas law relation $\rho = \frac{MP}{RT_{Gx}}$:

$$\left(\frac{h_G}{k_G}\right)\left(\frac{DP}{k\,RT_{Gx}\,p_{BM}}\right) = \frac{c_p\rho D}{k}\left(\frac{Sc}{Pr}\right)^{\frac{2}{3}} = \left(\frac{Pr}{Sc}\right)^{\frac{1}{3}}$$

Hence from Equation (18)

$$\left(\frac{T_{Gx}-T_s}{T_G-T_s}\right) = \frac{1}{f(a)}\left(\frac{Pr}{Sc}\right)^{\frac{1}{3}}\left(\frac{p_{Gx}-p_s}{p_G-p_s}\right)\frac{f_H(x)}{f_D(x)} \quad \ldots.(19)$$

Now when $x = 0$, $\frac{f_H(x)}{f_D(x)} = 1$, and when $T_{Gx} = T_G$ and $p_{Gx} = p_G$ (i.e., when $x = \infty$ in the bulk of the gas) $\frac{f_H(x)}{f_D(x)} = f(a)\left(\frac{Sc}{Pr}\right)^{\frac{1}{3}}$. $\frac{f_H(x)}{f_D(x)}$ will vary regularly with respect to x between these two limiting values and will

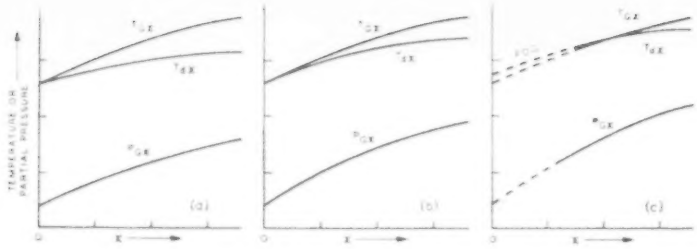

Fig. 5. Boundary layer conditions for a cooler-absorber: (a) no supersaturation; (b) supersaturation incipient at $x = 0$; and (c) supersaturation at $x = 0$ and outwards.

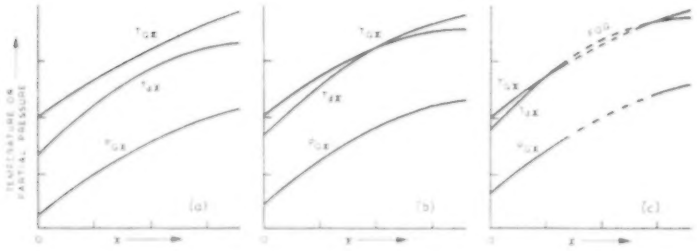

Fig. 6. Boundary layer conditions for a cooler-absorber: (a) no supersaturation; (b) supersaturation incipient somewhere in boundary layer or bulk of gas; and (c) supersaturation somewhere in boundary layer or bulk of gas.

show no maxima or minima. Precisely how it varies might be obtained from a study of turbulence in the boundary layer, but it is noted that, for most systems, the value of $\left(\frac{Sc}{Pr}\right)^{\frac{1}{3}}$ does not lie below 0.7 or rise above 1.1, so that the change in the value of $\frac{f_H(x)}{f_D(x)}$ is not normally great. Thus the assumption that it changes linearly with respect to either $\left(\frac{p_{Gx}-p_s}{p_G-p_s}\right)$ or $\left(\frac{T_{Gx}-T_s}{T_G-T_s}\right)$ will not be in much error. It is chosen here to vary linearly with respect to $\left(\frac{p_{Gx}-p_s}{p_G-p_s}\right)$ as follows:

$$\frac{f_H(x)}{f_D(x)} = 1 + \left[f(a)\left(\frac{Sc}{Pr}\right)^{\frac{1}{3}} - 1\right]\left(\frac{p_{Gx}-p_s}{p_G-p_s}\right) \quad \ldots.(20)$$

and hence putting Equation (20) in (19):

$$\left(\frac{T_{Gx}-T_s}{T_G-T_s}\right) = \frac{1}{f(a)}\left(\frac{Pr}{Sc}\right)^{\frac{1}{3}}\left(\frac{p_{Gx}-p_s}{p_G-p_s}\right)\left\{1 + \left[f(a)\left(\frac{Sc}{Pr}\right)^{\frac{1}{3}} - 1\right]\left(\frac{p_{Gx}-p_s}{p_G-p_s}\right)\right\} \quad \ldots.(21)$$

Equation (21) is easily used to plot the gas condition passing through the boundary layer and it can then be observed whether the condition passes into the super-saturated region, where fog is liable to form. This matter will be discussed in greater detail later in a calculated example and with reference to Fig. 7.

Special Case

A special and common case exists where $\frac{1}{f(a)}\left(\frac{Pr}{Sc}\right)^{\frac{1}{3}} = 1$. Equation (21) then reduces to:

$$\left(\frac{T_{Gx}-T_s}{T_G-T_s}\right) = \left(\frac{p_{Gx}-p_s}{p_G-p_s}\right) \quad \ldots.(22)$$

which is exact, for there is no change in $\frac{f_H(x)}{f_D(x)}$ in passing through the boundary layer. It will be noted that Equation (22) is precisely the same as the operating line given by Equation (6). Both lines are straight and run from the gas inlet condition $(T_G, P_G)_i$ to the equilibrium condition (T_s, p_s). Thus, if one is fortunate, it is very simple to decide whether fog is liable to form in the boundary layer and then later, perhaps, in the bulk of the gas.

The analytical solution of Johnstone, Kelley and McKinley,[7] which only applies to a cooler-condenser, can be obtained from Equation (19). At the interface the equation reduces to:

$$\left(\frac{dT_{Gx}}{dp_{Gx}}\right)_{x=0} = \frac{1}{f(a)}\left(\frac{Pr}{Sc}\right)^{\frac{1}{3}}\left(\frac{T_G-T_s}{p_G-p_s}\right) \quad \ldots.(23)$$

Now the slope of the equilibrium vapour pressure line at the interface condition (T_s, p_s) is given by the Clausius equation:

$$\left(\frac{dT_{dx}}{dp_{Gx}}\right)_{x=0} = \frac{RT_s^2}{\lambda p_s} \quad \ldots.(24)$$

where λ is latent heat of vapourisation. Hence it is obvious that fog is liable to form in a cooler-condenser if

$$\frac{1}{f(a)}\left(\frac{Pr}{Sc}\right)^{\frac{1}{3}}\left(\frac{T_G-T_s}{p_G-p_s}\right) < \frac{RT_s^2}{\lambda p_s} \quad \ldots.(25)$$

Johnstone and colleagues give graphs showing the boundary conditions for fog formation for vapours of water, n-butyl alcohol and sulphur.

Detrimental Effect of Fog Formation

It is important to emphasise the detrimental effect of fog formation, especially where a valuable vapour is concerned. The size of fog particles normally lies in the range of 0.05 to 5μ and they are consequently difficult and expensive to trap and recover. In special cases, further cooling will cause the liquid fog particles to turn solid, and, if the material is liable to react with the atmosphere, it will be in a particularly active state and special precautions will be needed to recover it in massive form by remelting.

Once fog forms in the boundary layer or in the bulk of the gas, it is liable to spread rapidly. The fine droplets will be exceedingly good transferers of heat from the gas stream

to the liquid-gas interface by radiation. Thus the whole balance between mass and heat transfer will be upset and the bulk gas-condition will progress rapidly towards the super-saturated region, although previously it may have been far from it. The operating line would bow towards the vapour-pressure curve of the volatile material much more strongly than any of the equations set forth here would suggest.

Calculated Example

A nitrogen stream at 90°C contains n-butyl alcohol with a partial pressure of 0.05 atm., which is to be absorbed in an inert solvent used in sufficient quantity to maintain a constant equilibrium condition (30°C, 0.001 atm.). It is desired to know whether there is any likelihood of fog forming either in the boundary layer or in the bulk of the gas.

Fig. 7 shows the information supplied together with the vapour-pressure curve for pure n-butyl alcohol.

To calculate $\left(\frac{Pr}{Sc}\right)$, the values of c_p, ρ and k should be estimated for the gas mixture, but little error is introduced by using the values for nitrogen, since the vapour concentration is small. Also as $\left(\frac{Pr}{Sc}\right)$ is almost invariant with the temperature, at 0°C or any temperature up to 100°C

$$\left(\frac{Pr}{Sc}\right) = \frac{c_p \rho D}{k} = \frac{0.247 \cdot 0.0785 \cdot 0.273}{0.0140} = 0.379$$

$$\left(\frac{Pr}{Sc}\right)^{\frac{1}{3}} = 0.524 \qquad \left(\frac{Pr}{Sc}\right)^{\frac{1}{4}} = 0.724$$

From Equation (9) at the gas inlet

$$a = 0.524 \frac{9.8}{6.9} \ln\left(\frac{1-0.001}{1-0.050}\right) = 0.0376$$

From Equation (8)

$$f(a) = \frac{1-0.9632}{0.0376} = 0.979.$$

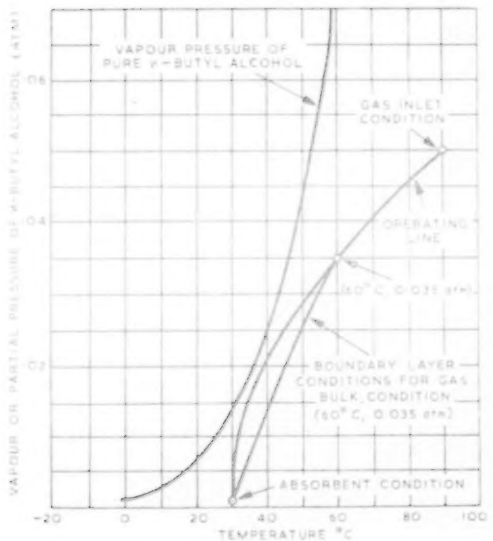

Fig. 7. Conditions in an n-butyl alcohol cooler-absorber.

Hence transfer of sensible heat by vapour diffusion can be neglected. Also at the gas inlet

$$p_{BM} = \frac{0.999-0.950}{\ln \frac{0.999}{0.950}} = 0.968$$

and

$$\frac{p_{BM}}{P-p_G} = \frac{0.968}{1-0.05} = 1.018.$$

Hence this factor in Equation (5) can be neglected and Equation (6) can be used which describes the whole operating line

$$\frac{p_G-0.001}{0.049} = \left(\frac{T_G-30}{60}\right)^{0.524}$$

This equation is shown in Fig. 7. No fog will form in the bulk of the gas, since this operating line does not cross the vapour-pressure line for the pure volatile material. However, it comes close to doing so, and, if the inlet gas temperature were to fall by 5°C, there may be a danger of fog formation.

Equation (21) describes the gas condition in the boundary layer

$$\left(\frac{T_{Gx}-30}{T_G-30}\right) = 0.724 \left(\frac{p_{Gx}-0.001}{p_G-0.001}\right) \left[1 + 0.382 \left(\frac{p_{Gx}-0.001}{p_G-0.001}\right)\right]$$

This curve has been drawn in Fig. 7 for one bulk gas condition (60°C, 0.035 atm.). It is apparent that there is less likelihood of fog formation in the boundary layer than in the bulk of the gas.

The example is interesting since it demonstrates that the curve giving conditions in the boundary layer is straighter than the operating line. Thus for an operating line bowed to the left, as illustrated in Fig. 7, it is quite possible that fog will form in the bulk of the gas while none forms in the boundary layer, though, if the operating line were to fall severely into the super-saturated region, boundary layer fog would appear first. If the operating line is bowed to the right—a more unusual case—the curve of conditions in the boundary layer will still be straighter than the operating line and, therefore, fog will form much more readily in the boundary layer than in the bulk of the gas.

Conclusion

A procedure for calculating the surface-area requirements of cooler-condensers and cooler-absorbers has been discussed in detail and it has been pointed out that much simplification results if the problem concerns a dilute vapour and if the ratio $\left(\frac{Pr}{Sc}\right)$ is unity or close to unity. Emphasis has been placed upon the disadvantages of fog formation, and it has been shown how to decide if there is any possibility of its occurrence either in the boundary layer or in the bulk of the gas.

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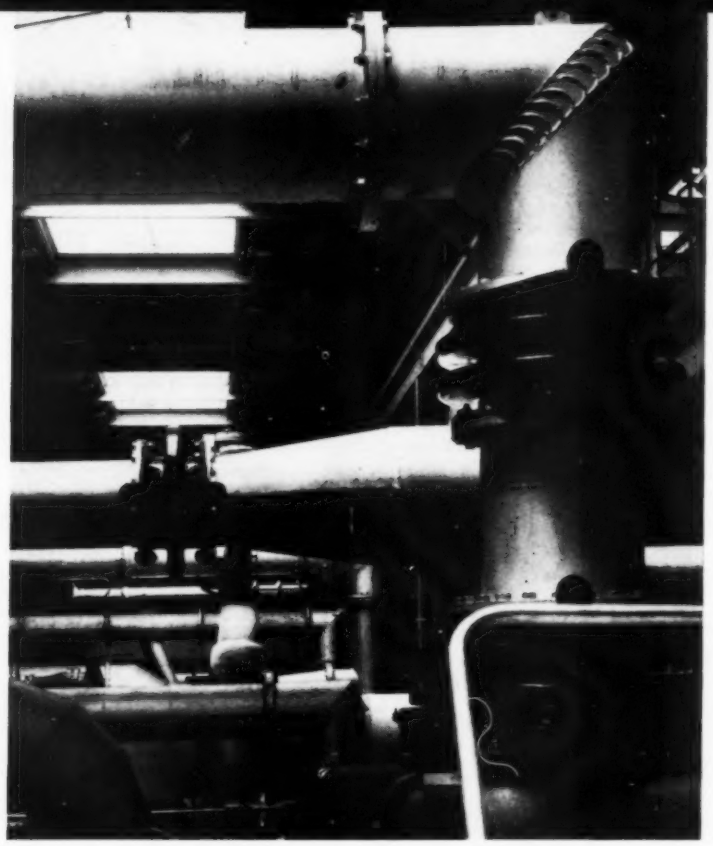


CASCADE CORNERS FOR DUCTS OF CIRCULAR CROSS-SECTION

by N. A. DIMMOCK,
B.Sc.(Eng.), A.M.I.Mech.E.

The development of a design of cascade corner for circular pipes is described and its performance compared with that of bends. The recommended method of manufacturing the corners is also outlined

EXPERIMENTS on cascade corners for circular cross-section ducting began when it was found that many test rigs for gas turbine component research were suffering from very poor velocity profiles at entry to either their airflow-measuring section or to the test section. A frequent cause of the trouble was an upstream elbow or a bend of small radius to diameter ratio. Lack of space usually prevents the use of a bend having the large ratio of radius to diameter necessary for a low-pressure loss; even if this is achieved, such a bend still leads to an extremely poor velocity profile at outlet with double helical secondary flows.

Nearly all existing work on bladed corners[1 to 7] has been confined to rectangular section ducts, although Kröber has stated[4] that the shape of the cross-section was of no consequence if well-designed blade profiles were used. Kröber, however, in common with all other workers, had a good inlet velocity profile to the test corner, whereas in practical ducting layouts a thin boundary layer is seldom found. Work by Winter[8] has shown that the best blade form for rectangular corners is probably that of the sheet-metal blade, as would be expected from cascade theory, provided that the stagnation point is at the leading edge. Moreover, the sheet-metal blade is obviously the simplest to manufacture.

The problem is to provide a corner which will accept a workaday inlet velocity profile, give a reasonably even outlet velocity profile, and have a low loss as far as is compatible with the second criterion. It will also have to be robust, compact and straightforward to manufacture.

Bearing in mind the points so far mentioned, a test rig was designed in which no special precautions were taken to obtain a very good velocity profile at the entrance to the test corner. In fact, the test rig was not connected to the suction side of the fan, as is so often done to obtain good entry conditions. Fig. 1 shows the arrangement of the test pipework. Air supplied by a 30-h.p. centrifugal fan was led via a gauze and an accelerator into a four-diameter length of straight, 6-in. diameter ducting in which a datum pitot-static tube was set. At the end of the settling length came the test corner assembly, which was followed by a further six diameters of straight pipe. Provision for traversing was made one diameter upstream and downstream of the corner and, thereafter, at two-diameter intervals. A cylindrical pitot-tube was used for measuring total pressure, and this had an outside diameter of $\frac{3}{16}$ in. and spanned the pipe. This instrument could slide radially through rotatable rings which were located by means of spigots, between flange faces of adjacent pipe lengths (see Fig. 1 inset). Air angles were not measured, but the total head tube was rotated as required to obtain the maximum pressure reading at each point of the traverse.

As a cheap and ready method of making-up test corners, the blades were set in Plasticine within a rectangular wooden frame, which was in turn bolted between two 45-degree flanges and stub pipes (see Fig. 1). The Plasticine was faired to form the intersection ellipse. When 12-in. diameter corners were later tested, only fabricated cascades were used. The cascade nomenclature is shown at the bottom of Fig. 1.

SYMBOLS USED

Geometric

D = diameter of pipe;
L = length of pipe;
R = radius to centre-line of a bend;
c = chord of blade;
s = pitch of blades;
α_1 = air inlet angle;
α_2 = air outlet angle;
β_1 = blade inlet angle;
β_2 = blade outlet angle;
i = incidence $= \alpha_1 - \beta_1$;
δ = angle of deviation $= \beta_2 - \alpha_2$
θ = camber angle of blade;
ζ = stagger angle;
t = blade thickness
r and θ = traverse co-ordinates.

(see also Fig. 1A.)

General

C_f = overall pressure loss factor;
C_L = lift coefficient;
f_{max} = maximum stress;
$\triangle P$ = overall pressure drop between reference planes;
V = velocity;
$\overline{V}$ = mean velocity;
Z = section modulus of blade in bending;
λ_s = straight pipe friction factor;
ρ = mass density (slugs/cu. ft); and
ω = local loss of total pressure.

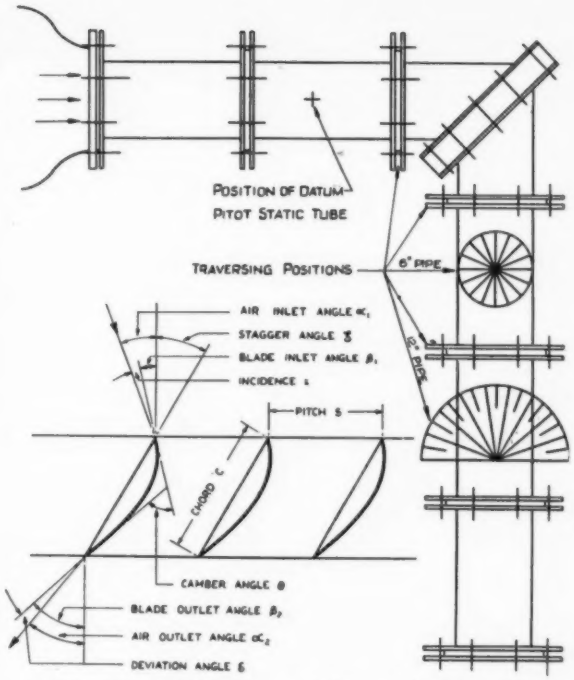


Fig. 1. Annotated diagram of the test rig layout. The lower diagram gives the cascade notation.

Test Rig Characteristics and Methods of Measurement

The mean velocity in the 6-in. test pipe was about 200 ft/sec, the pipe Reynolds number being, therefore, nearly 6.4×10^5. The fan characteristic was such that the velocity in the 12-in. ducting was about halved, the Reynolds number remaining the same as before. The ducting sections were assembled without the corner so that the basic friction factor, λ_s, could be found. By measuring the pressure drop, $\triangle P$, down the length of straight pipe, L, λ_s was found to be 0.018 from

$$\lambda_s = \frac{\triangle P}{\frac{1}{2}\rho\overline{V}^2} \frac{D}{L}.$$

This value agrees with published information on friction in smooth pipes.

An example of the upstream velocity profile for the 6-in. rig is shown in Fig. 2, where it can be seen that the boundary layer thickness is nearly 1 in., and, with less acceleration from the fan, the larger rig had a slightly thicker upstream boundary layer. Aerodynamically, this profile is rather poor, but it is representative of a practical pipe-flow for which a suitable design of corner was required.

All the total head pressures were measured on a water manometer as differences from the datum total head, and were corrected to a mean dynamic head for any one test. Thus, the mean loss coefficient, C_f, was obtained graphically from:

$$C_f = \frac{\int_0^R \int_0^{2\pi} \frac{\omega}{\frac{1}{2}\rho\overline{V}^2} \, d\theta dr}{\frac{\pi}{4} D^2} = \frac{\triangle P_{corner}}{\frac{1}{2}\rho\overline{V}^2}$$

where θ is the angular register of the traverse diameter, as shown in Fig. 1, r is the radius, and ω is the loss of total pressure between corresponding points upstream and downstream of the corner. Geometrical correspondence was used in calculating the loss, as this gives a close enough approximation to the true value for all practical purposes.

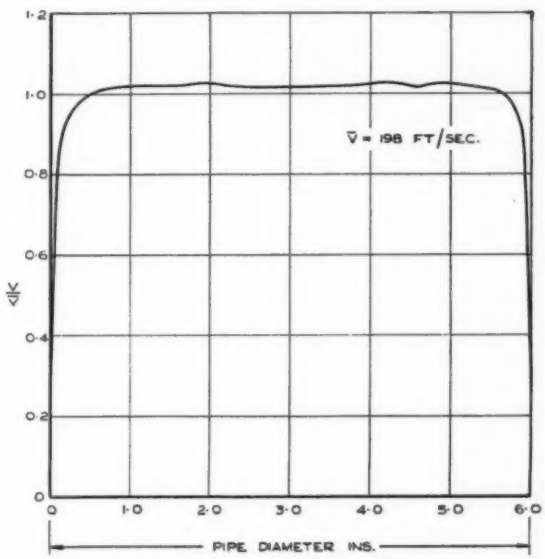


Fig. 2. A typical velocity distribution one diameter upstream.

Details of the Experiments

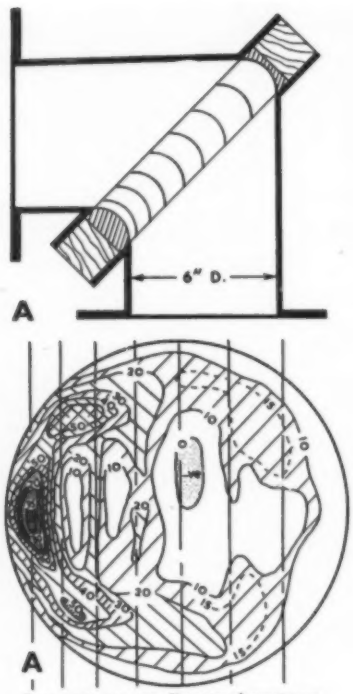
As a preliminary, the corner was tested without blades, and, as may be expected, the loss was very large with a large area of separated flow at the inside due to the large opposing pressure gradients. The loss contours are shown in Fig. 6 alongside the result of the next preliminary trial of the corner when fitted with only three blades. Although still a very poor result, it shows the remarkable improvement effected by such a crude arrangement. For the remainder of the preliminary tests, only diametral traverses in the plane of the corner were made, as they afforded enough information to assess the performance of cascades

having different numbers of blades and different spacings. The blades were sheet-metal circular arcs of 90-degree camber and of 2-in. chord, rounded at the leading edge and sharpened at the trailing edge. The best arrangement of blades found by successively halving the pitching towards the inside of the corner was with seven blades set at $\frac{1}{16}$, $\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$ and $\frac{1}{4}$ of the ellipse major axis; extra blades towards the outside increased the loss there without improving the velocity profile. Baulin and Ideltchik[5] had suggested that an arithmetic progression was the best arrangement, and the previous best spacing approximated to this. Therefore, the seven blades were re-arranged slightly so that they were in A.P., with a minimum pitch/chord ratio, s/c, of 0.31 and a mean $s/c = 0.53$.

It is interesting to note that this mean value is about the best for 90-degree impulse blades as is indicated by plain cascade tests. With this corner, the peak loss was slightly higher than the previous best, but the overall distribution was better and a full three-dimensional traverse was completed, giving the result shown in Fig. 3. Despite the low value of the mean-loss coefficient, the contours still show too high a peak of loss at the inside of the corner. In addition, although no yaw measurements were taken, it was obvious from the traverse parallel to the blades that the air was not being deflected through 90 degrees.

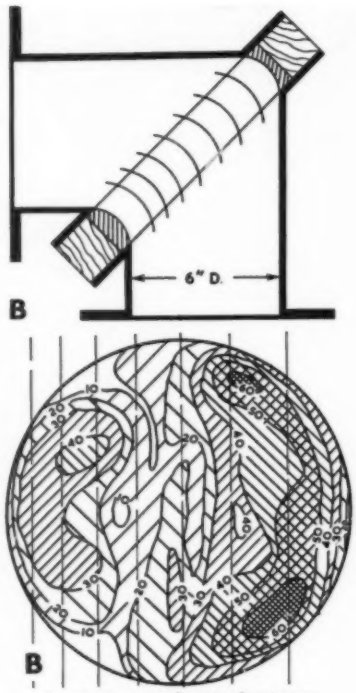
Many detail tests were then undertaken with different blade profiles; retaining the arrangement of seven blades in A.P. The profiles tested included circular arcs of larger chords; circular arcs plus additional straight extensions; circular arcs with straight extensions, but scaled down to a 2-in. chord; and circular arcs plus straight extensions but having camber angles greater than 90 degrees. An analysis of the performance of all these tests is not feasible here, but most of the modified corners showed an improvement in outlet velocity distribution; usually at the expense of a higher overall loss coefficient. Fig. 4 shows the worst result and is a warning against overdoing the deflection and so transferring the high loss to the outside of the corner.

With all the blades of 90-degree camber, under-deflection was noticeable, and it became obvious that deviation would have to be allowed for, even although this implied that the corners would then be unidirectional, a feature hitherto considered undesirable. However, once this feature was accepted, blade profiles based on circular arcs were no longer necessary; in fact, theoretical work by Kröber[4] had already suggested others forms as being better. An



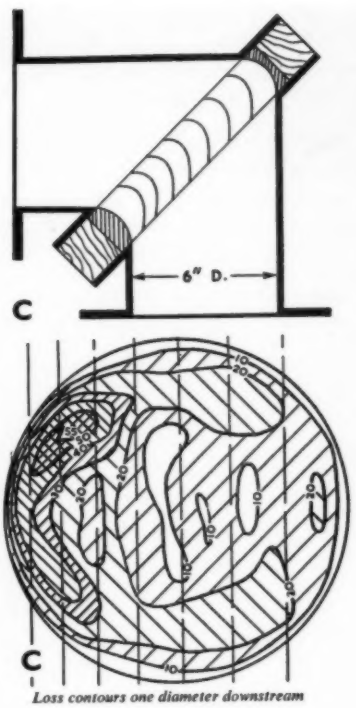
Loss contours one diameter downstream.

Fig. 3. Corner No. 3.



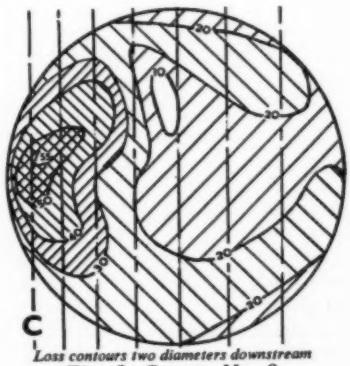
Loss contours one diameter downstream

Fig. 4. Corner No. 7.



Loss contours one diameter downstream

A		B		C	
Chord ...	2.0 in.	Chord ...	4.0 in.	Chord ...	2.0 in.
$\frac{s}{c}$ mean ...	0.53	$\frac{s}{c}$ mean ...	0.26	$\frac{s}{c}$ mean ...	0.53
$\frac{s}{c}$ min. ...	0.31	$\frac{s}{c}$ min. ...	0.155	$\frac{s}{c}$ min. ...	0.31
Camber, θ	90°	Camber, θ	100°	Camber, θ	100°
Stagger, ζ	0°	Stagger, ζ	5°	Stagger, ζ	15°
c_f	0.16	c_f	0.32	c_f	0.20



Loss contours two diameters downstream

Fig. 5. Corner No. 9.

examination of his theoretical blade shape for a 90-degree corner showed that it was very nearly a parabolic arc, having a camber angle of 100 degrees, and having the position of maximum camber 0.4 chord from the leading edge.

Chord parabolic blades of 2 in. were made, and eight of them fitted across the corner with an even pitch/chord ratio of 0.47, and a stagger of +11 degrees as recommended by Kröber. Only a few traverses were taken with this arrangement, as a very high peak loss showed up at the inside of the corner in spite of the extra blade. The cascade was rebuilt with seven blades in A.P. as before, and an allowance of 8 degrees was made for the deviation in accordance with normal two-dimensional cascade theory[9] and using the mean pitch/chord ratio. This necessitated re-staggering the blades at +15 degrees so that the incidence was now −2 degrees. The result is shown in Fig. 5.

The outlet velocity distribution was less peaky than from any of the corners previously tested, and the mean loss coefficient of 0.20 less than that of most. As a further check, a fabricated 12-in. corner was tested having blades of the same chord, profile and inside pitch, the A.P. being continued across the ellipse. The result was substantially the same as for the 6-in. corner with a mean loss coefficient of 0.21. The additional 1% loss was less than expected from a consideration of the far-from-perfect welded construction.

Final Choice of Corner

At this stage in the experiments it was thought that any further improvement could only be small in relation to the length of time that could be spent in achieving it. The target of a good downstream velocity profile with a reasonably low pressure loss had been reached with the cascade of parabolic arc blades in A.P. which were staggered to allow for deviation. The success of this corner was probably due to the accelerating inside passage preventing the thick boundary layer from breaking away in that region. In fact, because of the variation in pitching and of the allowance for deviation being based on the mean pitch-chord ratio, the air tends to be slightly over-deflected at the inside of the corner, whilst towards the outside it is under-deflected; that is, the local flow is directed towards the walls, so preventing separation.

Design Details

Complete design data for the chosen corner are given in Figs. 7 and 8 and in a form suitable for drawing-office use. The information is self-explanatory, except for the derivation of the blade chord. From an aerodynamic viewpoint, the chord of the blades is not dependent on pipe diameter, so long as the pitch/chord ratio remains unchanged. However, considerations of strength indicate that larger chords are necessary with large-diameter ducts. Therefore, Equation (1) in Fig. 8 is an empirical expression which will give an acceptable chord length for a well-proportioned corner suitable for all sizes of ducts and for air speeds giving a Mach number of less than 0.5.

The thickness of the sheet-metal blades is not specified in the design data as this will depend to some extent on local conditions and opinions and on the upstream condition of the flow. However, for the sheet-metal blade of thickness t in. the section modulus is found to be:

$$Z = 0.94\,t^3 + 0.0658\,c^2\,t \text{ in.}^3$$

and an example has been worked for the following typical conditions:

V = 400 ft/sec; air pressure in duct = 5 atmospheres; maximum permissible stress = 10,000 lb/sq. in. lift coefficient, C_L, based on s/c = 0.55.

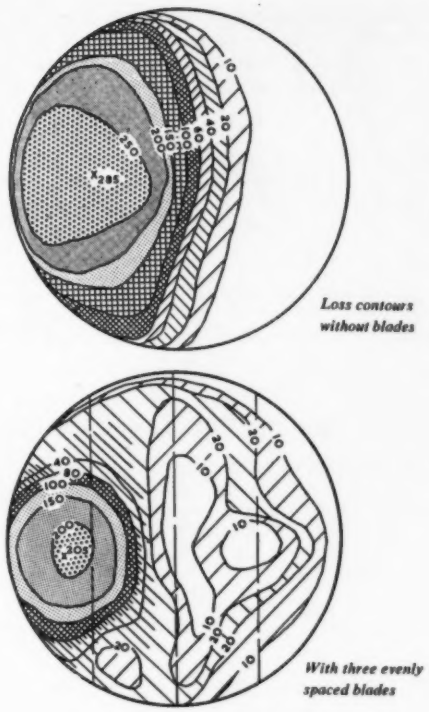


Fig. 6. Corners 1 and 2.

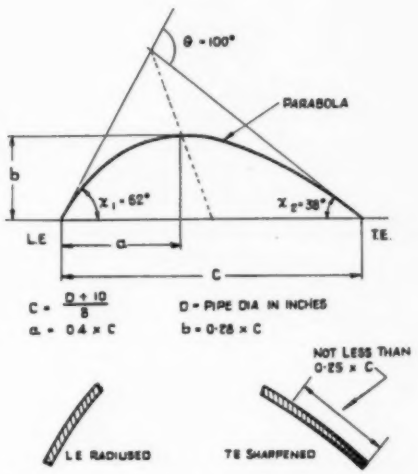


Fig. 7. Design data I for sheet-metal blade profiles.

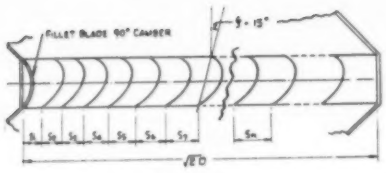
The lift is assumed to be uniformly distributed over the longest blade and the blade to be simply supported at the ends. Thus:

$$\frac{f_{max}}{\frac{1}{2}\rho V^2} = \frac{D^2\,(D + 10)}{27.34\,t^3 + 0.02986\,t\,(D + 10)^3}$$

with $\frac{1}{2}\rho V^2$ in lb/sq. in.

Fig. 9 shows the result of this example in the form of required blade thickness plotted against pipe diameter.

It should be noted that close upstream obstructions, and in particular a valve, can give rise to such a violently distorted flow that vibration of the blades can lead to their



D = Diameter of pipe in inches.

$$C = \frac{D + 10}{8} \qquad \ldots.(1)$$

Number of blades: $N = \frac{2.6\,D}{C} - 1$ .... (2)

(take to nearest integer)

$$S_1 = 0.3 \times C \qquad \ldots.(3)$$

Constant Difference in the *A.P.* = Δ.

$$\Delta = \frac{\frac{2.83\,D}{N+1} - 2S_1}{N} \qquad \ldots.(4)$$

Any Pitch $S_n = S_1 + (n-1)\,\Delta$ .... (5)

Fig. 8. Design data II for cascade corners in circular pipes.

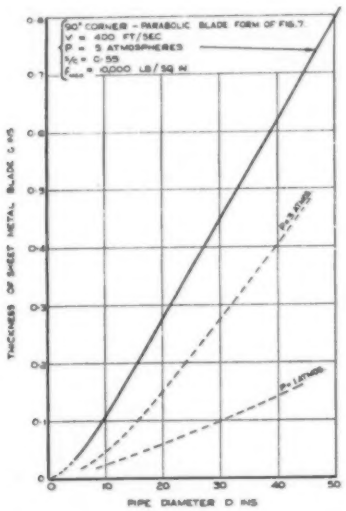
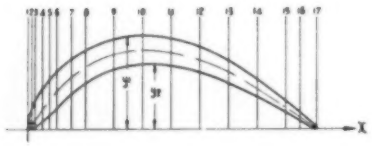


Fig. 9. Blade thickness and pipe diameters for some typical conditions.



Station	% AGE OF CHORD x	y1	y2
1	0	2·15	2·15
2	1·25	7·20	0·05
3	2·50	10·05	0·35
4	5·0	14·35	2·25
5	7·5	17·80	4·75
6	10·0	20·35	7·40
7	15·0	25·00	12·25
8	20·0	28·10	16·25
9	30·0	31·80	21·50
10	40·0	32·90	25·25
11	50·0	31·80	27·65
12	60·0	28·90	27·50
13	70·0	24·25	26·60
14	80·0	18·15	21·75
15	90·0	10·50	14·15
16	95·0	6·20	9·20
17	100·9	0·60	0·60

t/c = 10%

LE RADIUS = 12% t

TE RADIUS = 6% t

	x	y
LE CENTRE	1·40	1·20
TE CENTRE	100·3	0·60

} ½c

Fig. 10. Suggested blade profile for high loading.

failure. With such an upstream condition, there seems little point in using the refinement of a cascade corner. From Fig. 9 it would appear that, for the conditions of the example, fabricated blades of streamline section would be better for corners in ducts where the thickness of the plain sheet-metal blade becomes excessive—say at $D = 25$ in. for 5 atmospheres pressure, or $D = 36$ in. for 3 atmospheres pressure. A suggested blade form is shown in Fig. 10; the camber line or "backbone" of the section being the same parabola as that of the sheet-metal blade.

Manufacturing Techniques

A manufacturing technique was developed, in conjunction with the workshops, after tests on fabricated corners had shown that the loss was increased considerably by bad welding and by welding the blades to the ellipse internally. The method strongly recommended is as follows.

An intersection ellipse of correct width is first welded to the 45-degree faces of the two branches forming the corner; the circular-arc fillet blade can then be fitted into the inside and welded. A hand grinder is then used to clean up all the internal seams and welds to form a smooth, continuous surface (no steps). The ellipse is then marked out and slotted to receive the blades which project sufficiently to be welded on the *outside* surface of the ellipse. The surplus metal can then be trimmed off.

Apart from the obvious aerodynamic advantages of externally welding the blades, there is a considerable practical advantage in avoiding having to introduce the welding rod into acute inaccessible angles, as this nearly always results in the undercutting and weakening of the blade. On the other hand, care must be taken to avoid leaving cavities between the blade surfaces and the clearance slots (i.e., aim for an initial good fit and good penetration of the weld) if a finishing process such as shot-blasting and aluminium spraying is used. Damage has been caused to downstream components by shot which had lodged in the cavities and had been temporarily retained there by the protecting skin of aluminium.

In the sheet-metal workshop at the National Gas Turbine Establishment (N.G.T.E.) fitments were made for all the most commonly used sizes of corner, so that the oxy-acetylene profiling cutter could burn the slots with a high degree of accuracy. Fig. 11 shows the neatness of the finished article with no rough welding on any wind-swept surface.

Comparison with Other Work

The final choice of corner does not conflict to any great extent with the results from rectangular section corners given by Prandtl[1] or Baulin and Ideltchik,[5] the optimum mean pitch/chord ratio lying between the two values suggested by those workers, but the minimum pitch/chord ratio being considerably smaller than that suggested by either. The necessity for the low value of s/c at the inside of the corner is probably due to the more complicated flow pattern and the rather awkward passage shapes. The boundary layer at the inlet to the cascade is also important, as a thick boundary layer is very likely to separate unless extreme measures are taken to ensure its stability. All other workers have, by intent, had good aerodynamic inlet conditions, which are ideal for fundamental research but not representative of practical ducting conditions.

The same comments would apply to the results of Kröber[4] and Salter,[7] who obtained losses of only 13% and 12% of a velocity head respectively. Both had very good inlet velocity distributions with thin boundary layers, and the approximate value of the induced drag (calculated using the methods in Reference [10]) resulting from the non-uniform inlet conditions almost accounted for the

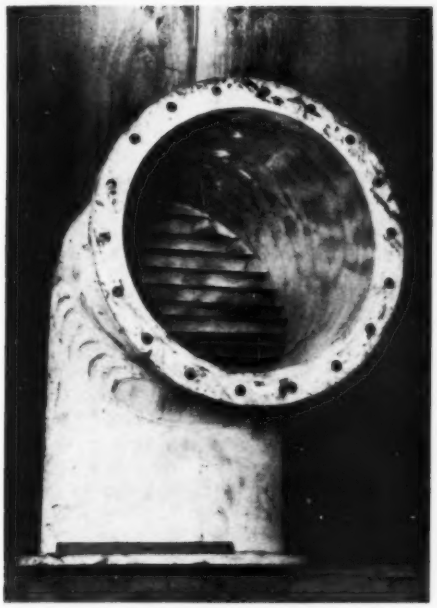


Fig. 11. The finished corner.

difference of 8% in loss coefficient.

Although between 500 and 1000 corners to the basic design of Figs. 7 and 8, and covering a size range of from 6-in. to 48-in. diameter are in use at the N.G.T.E., no further tests have yet been made. Confirmation both of the value of the loss coefficient and of the good outlet velocity profile is provided by the results of tests on a corner used in the jet pipe of a well-known vertical-take-off machine. Here it was found that, outside the boundary layer, the velocity variation at 1.5 diameters from the corner was not more than 8%. The measured loss coefficient was 0.2.

A design data sheet for cascaded corners for water pipes is used at the Mechanical Engineering Research Laboratory (M.E.R.L.), East Kilbride, and is based on the design given in this article. Modifications include a return to

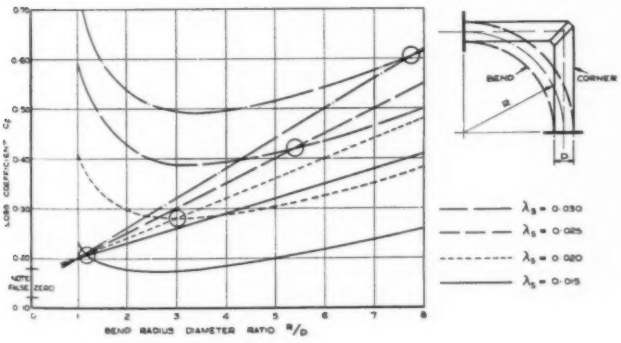


Fig. 12 (above). Comparison between losses in corners and smooth bends.

Fig. 13. Curve for determining whether corner or bend will give the lower loss for given values λ_s against R/D.

circular-arc blades (for practical reasons), an effective camber of about 100 degrees and zero stagger angle, thus permitting flow in either direction. As the pipework has only recently been commissioned, no test results are yet available. Some work at Cambridge on cascades at sharp elbows in water pipes[12] gives a best result with a loss coefficient of just over 0.3.

The comparison between the performance of corners and that of bends is dependent on the ultimate requirement—low loss or good velocity distribution. The general problem may be considered of joining two flanges at right angles and in the same plane with a duct. Alternative arrangements are given in the inset in Fig. 12. Gray[11] has correlated very many results and suggests the expression for the loss coefficient of a bend as:

$$C_f = (8 + 26\frac{D}{R})(\lambda_s - 0.0088) + \frac{\pi R}{2D} \cdot \lambda_s.$$

The term $(8 + 26\frac{D}{R})(\lambda - 0.0088)$ is referred to as the extra loss coefficient for curved flow, and the other term is the loss coefficient for an equivalent length of straight pipe.

The loss coefficient for the arrangement using a corner is given by:

$C_{f\,\text{corner}} = 0.20 + 2\lambda_s(\frac{R}{D} - 1)$, 0.20 being taken as the constant-loss coefficient for a well-made corner with stub pipes one-diameter long as in the tests.

Curves of $C_{f\,\text{bend}}$ and $C_{f\,\text{corner}}$ are plotted in Fig. 12 for values of λ_s covering the range likely to be found in practice. The intersection points are replotted in Fig 13 as λ_s against R/D, and the resulting curve determines whether a corner or a bend will give the *lowest loss* for given values of λ_s and R/D. It should be noted that the bend is considered to be smooth, and that the loss would be considerably higher for folded or segmental bends (lobster backs). If a good downstream velocity profile is of paramount importance, then a cascade corner might well prove to be superior in nearly all instances, as well as giving the most compact layout.

The author wishes to thank the Director, M.E.R.L., and Rolls-Royce Ltd. for permission to use their design data sheet and test results respectively.

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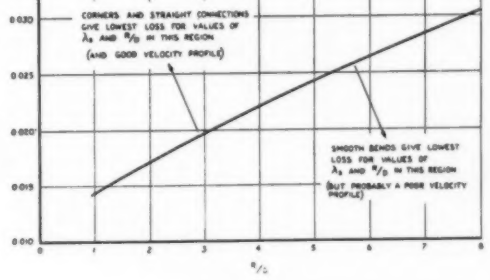
CORNERS AND STRAIGHT CONNECTIONS GIVE LOWEST LOSS FOR VALUES OF λs AND R/D IN THIS REGION (AND GOOD VELOCITY PROFILE)
SMOOTH BENDS GIVE LOWEST LOSS FOR VALUES OF λs AND R/D IN THIS REGION (BUT PROBABLY A POOR VELOCITY PROFILE)
R/D

SASOL:

WORLD'S LARGEST OIL-FROM-COAL PLANT

In the second article of this series* the authors deal with the two synthetic processes employed at the SASOL plant

by J. C. HOOGENDOORN and J. M. SALOMON, B.Sc. (Eng.), Ph.D.

IN contrast to the Kellogg synthesis with its circulating catalyst reactors, the Arge synthesis plant built by the Arbeit-Gemeinschaft Lurgi und Ruhrchemie (see Fig. 1) uses fixed-bed reactors. The Fischer-Tropsch plants built in Germany before and during World War II had a large number of relatively small reactor units to contend with the heat-removal problems. Extensive research on the rate of heat removal as a function of tube diameter and gas velocity has enabled Arge now to design much bigger units and to use much greater gas loads. The five Arge reactors at Sasol (four on line and one standby) have the same output of hydrocarbons as 75 small reactors of the pre-war German design. It is evident that this small number of big units represents a large saving in equipment and instrumentation costs.

Each reactor (Fig. 2) is approximately 42 ft long and has a diameter of 9 ft 8in. The reactor contains a tube bundle of 2052 tubes which are partly filled with catalyst. The catalyst charge, which is 40 m^3 for each reactor, is supported by a grate which is fitted a short distance below the lower tube plate. This grate is constructed in segments which can be mechanically released from the outside of the reactor to unload a charge of exhausted catalyst. On the shell side of the tube bundle, steam is produced at a pressure corresponding to the required reaction temperature. In the top of the reactor a steam heater is installed to heat the gas to the required operation temperature.

Feed gas, after heat exchange with the hot reaction-gas, enters the top of the reactor. This feed gas consists of fresh gas from the purification plant and reactor tail gas in a ratio of 1 : 2.3. The fresh gas is available at 325 psig and it is boosted by a centrifugal compressor together with the tail gas to a pressure of 360 psig, at which it enters the reactor. Each reactor has a fresh gas feed of 20,000 Nm^3/hr with a hydrogen : carbon-monoxide ratio of 1.7 : 1 to 1.8 : 1 and 13% methane. In the reaction, approximately 70% of the carbon monoxide is converted, whereas the amount of hydrogen consumed is approximately 1.5 times the CO consumption. The resulting tail gas has, therefore, a H_2 : CO ratio of about 2.0-2.2, i.e., higher than the fresh gas ratio. For a feed of 80,000 Nm^3/hr of fresh gas, a tail gas of about 40,000 Nm^3/hr is obtained containing all the original methane present plus some methane formed in the reaction, so that the tail gas contains approximately 25% of this hydrocarbon.

In a plant with only Arge reactors, this tail gas would be used as a feed to a further set of reactors after re-forming the methane to provide additional CO and H_2. In the integrated Sasol plant, however, the tail gas of the Arge section combines with a further 40,000 Nm^3/hr of fresh, purified gas and this combined gas is used as feed to the Kellogg synthesis units after re-forming of the methane. The Kellogg tail gas (about 30,000 Nm^3/hr) also joins the feed to the re-formers so that the methane re-formers receive approximately 110,000 Nm^3/hr of combined gas, from which they produce 160,000 Nm^3/hr of Kellogg feed gas. As the Kellogg synthesis requires an appreciably higher H_2 : CO ratio than the Arge synthesis, it is evident that the gas composition as obtained suits the integrated character of the plant with its two methods of synthesis. It is also evident that, for the Arge reactors operated in this way with a gas contraction of about 50%, the re-forming of methane is not essential. All methane re-forming can be done centrally on the combined gas to the Kellogg synthesis in which the methane would otherwise build up. Unlike the Arge reactors, apart from a small purge to remove inerts such as nitrogen and argon, all the Kellogg tail gas is re-used in the section.

Recycle Gas Boosting

Another difference between the two synthesis systems is the method of recycle gas boosting. The Arge reactors operate at approximately 360 psig, whereas the Kellogg synthesis is designed for a reaction pressure of 275 psig. The gasification plant is therefore designed to produce gas at a pressure high enough to give 325 psig exit from the Rectisol plant. This allows for the pressure drop through the methane re-forming section, and the gas enters the Kellogg synthesis section at 275 psig. In this synthesis plant, therefore, only the recycle gas needs to be boosted to the reactor inlet pressure. In the Arge synthesis, however, the higher reaction pressure is obtained by boosting the fresh gas and the recycle gas together. As for the Arge synthesis, no methane re-forming is required; only a relatively small pressure increase is necessary to obtain the desired operating pressure. The reaction temperature in the Arge reactors at the beginning of a run with fresh

* *The first article of this series was published in the May, 1957, issue of* British Chemical Engineering, *p.* 238.

catalyst is 200-230°C. To maintain the desired carbon monoxide and hydrogen conversion during the life of the catalyst, it is necessary to gradually raise the temperature, and the total temperature rise is 25-30°C. The reaction temperature is controlled by the pressure at which the boiler feed-water is allowed to evaporate outside the reactor tubes.

The Fischer-Tropsch catalyst is extremely pyrophoric. To load a reactor with catalyst, it is first necessary to purge the reactor system completely with dry inert gas. The fresh catalyst is stored in transport hoppers under inert gas. These hoppers are lifted by a hoist to the top of the open reactor, the hopper is connected to the reactor and the catalyst loaded into the reactor through the bottom valve of the hopper. Inert gas is passed through the reactor during the operation. After a completed run, the catalyst has to be discharged. However, the reactor still contains an appreciable amount of paraffin wax in the catalyst voids, and, to remove this, the catalyst is first extracted in the reactor with a suitable hydrocarbon fraction, and, after drying, is unloaded by gravity through the hinged catalyst-support grate and out through the bottom flange of the reactor.

Products of Reaction

The products obtained during the reaction consist of hydrocarbons ranging from methane to extra-hard paraffin waxes. At Sasol only hydrocarbons from C_3 upwards are regarded as products, the CH_4 and C_2's being re-formed to CO and H_2. Moreover, some carbon dioxide, reaction water and alcohols are formed. The water-soluble alcohols are collected in the condensed reaction water and passed to the central oxygenates recovery section which will be described in a subsequent article. The hydrocarbons produced condense as the temperature drops in the several units of the cooling train of each reactor and are collected separately. In this way, by partial condensation, a rough separation in boiling ranges is obtained. From the reactor bottom and wax separator a stream of hard wax, called "reactor condensate", is obtained. The heat exchanger supplies the "hot condensate"—medium-boiling hydrocarbons, and the condenser supplies the "cold condensate"—the lighter hydrocarbon oils, reaction water and water-soluble alcohols. To avoid corrosion in the cooler by the small amount of organic acid produced, a dilute caustic solution is sprayed into the top part of the cooler. The lye is collected together with the condensed reaction water.

Reactor condensate and hot condensate pass, through traps, to the appropriate run-down tanks and are transferred from these tanks to the work-up sections. The cold condensate flows to an oil-water separator tank which is kept under synthesis pressure to avoid emulsion formation. The separated oil flows through a trap into an intermediate light oil tank. The reaction water-lye mixture flows through a trap into a second separator tank; hydrocarbons separated here join the oil of the first separation. A portion of the reaction water, which is still alkaline, is pumped back to serve as a neutralising agent in the cooler; additional fresh lye is added to this stream. The remainder of the water is pumped to the central oxygenates recovery section.

The tail gas, which is now at about 35°C, still contains some of the lower hydrocarbons which have not condensed at this temperature. Before this tail gas is sent to the re-forming plant, carbon dioxide and residual hydrocarbons are removed at sub-zero temperatures in a plant similar to that used for the gas purification. The tail gas is cooled down by heat exchange and additional ammonia refrigeration and then subjected to a low-temperature wash with heptane to remove the hydrocarbons and, thereafter, washed with cold methanol to remove the carbon dioxide. Regeneration of the methanol is effected by expansion in a manner similar to that used in the gas purification plant. The "loaded" heptane is regenerated by expansion and fractionation. The fractionation supplies "light ends" as fuel gas, a C_3-C_4 fraction and a C_5+ fraction. From the C_5+ fraction, a side stream consisting of heptane is withdrawn and used again in the wash tower. The remainder of the C_5+ fraction joins the directly-condensed light oils for further work-up. The C_3-C_4 fraction which contains an appreciable amount of olefins, goes to a central catalytic polymerisation unit where the combined Kellogg and Arge C_3-C_4 product is treated.

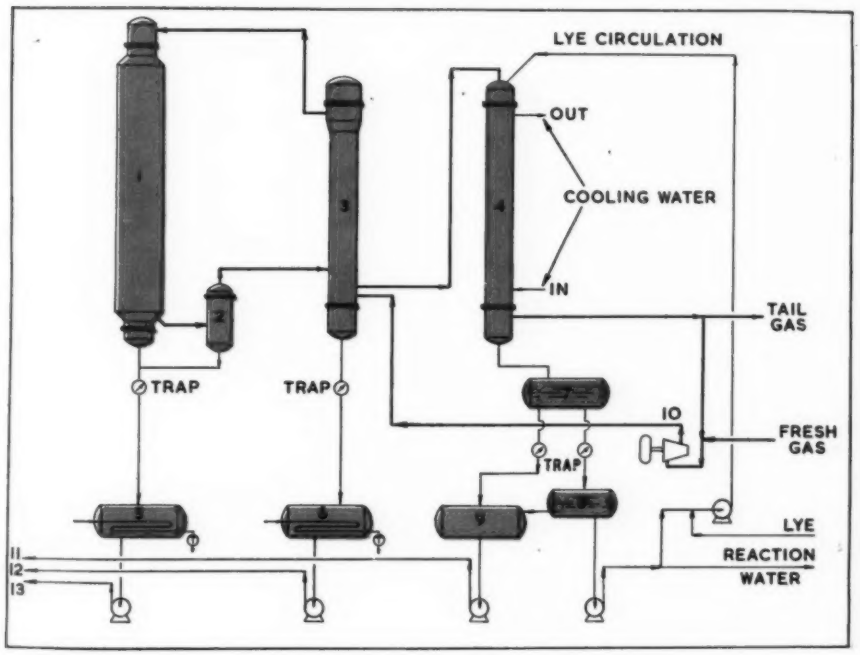

Fig. 1. Arge synthesis flow-sheet, showing: (1) reactor; (2) separator; (3) heat exchanger; (4) cooler; (5) reactor wax tank; (6) hot condensate tank; (7 and 8) oil-water separators; (9) cold condensate tank; (10) recycle blower; (11) cold condensate line; (12) hot condensate line; and (13) paraffin wax line.

The Arge plant, with four reactors running and one reactor on standby, is designed to produce a minimum of 53,000 metric tons a year of primary products (reaction products before refining). Of this quantity the high-boiling reactor condensate supplies approximately 16,000 m. tons; the medium-boiling range, hot condensate of the heat exchangers, supplies about 12,500 m. tons; and from the coolers comes about 8300 m. tons of low-boiling hydrocarbons and 2600 m. tons of water-soluble alcohols. In the deep cooling and scrubbing of the tail gas, a further 3000 m. tons of C_8+, 5300 m. tons C_5-C_7 and 5300 m. tons C_3-C_4 are obtained. (1 m. ton = 1000 kilos.)

Kellogg Synthesis—Circulating Catalyst Reactor

Catalyst Preparation. In the Kellogg synthesis reactors there is no *in-situ* regeneration or reactivation of the circulating catalyst. The catalyst activity is maintained at the desired level by daily removals of old or "equilibrium" catalyst and additions of a corresponding amount of new catalyst. For this reason, the preparation of the catalyst is an extremely important part of the synthesis. The basis of the Kellogg synthesis is a special type of iron ore promoted by a very small percentage of group I or III metals. The metal and its concentration are dictated by the desired product distribution. The catalyst preparation section consists of two main process units: a catalyst-manufacturing unit and a steam-iron hydrogen plant. The hydrogen plant is a conventional steam-iron hydrogen process producing 99.7% pure hydrogen at a normal capacity of 350,000 standard cu. ft a day. At the time of writing, the hydrogen plant is being extended and will have a capacity of some 800,000 s. cu. ft a day.

Iron ore is brought into the catalyst-manufacturing plant by either rail cars or trucks and is off-loaded, through a grate which will pass a maximum of 1-in. mesh material, into a steel track hopper. The oversize is first broken before it can be used. Material is picked up from the hopper by a belt conveyor attached to the bottom of the hopper. This discharges into a bucket elevator which charges the ore to a rotary drier. For the ore to be accurately metered to the fusion furnace it must be thoroughly dry. The ore, therefore, is dried in a rotary indirect-direct-heat, gas-fired drier to a final moisture content of about 1%. When properly fired, the equipment will produce the dried ore at a maximum temperature of 250°F. The flue gases leaving the drier contain fine particles of ore which are trapped in a cyclone before the gases are admitted to the atmosphere. The ore discharge from this cyclone drops into the screw conveyor which handles the larger pieces of ore.

The dried ore is then conveyed through a chute to the feed trunnion of a rod mill. This mill, the shell of which has replaceable steel liners, grinds the feed with steel rods to a size of 100% −16 mesh. This is the optimum size for use in the feeding device which accurately measures the catalyst components to the fusion furnace. The −16 mesh material discharges through a screw conveyor into a bucket elevator, and this raises the ore into a storage bin or a mixing hopper. A valve is provided in the discharge chute from this conveyor to control the direction of flow of the ore.

Components of the catalyst are metered by means of a continuous-disc metering device to the arc furnace, where fusion takes place. The material discharged from the feeder disc is collected in a funnel and flows by gravity through a bifurcated feeder pipe to both sides of the electrodes of the furnace below. The furnace is water-jacketed, is run on a.c. current, and operates as an open-arc furnace. Three 6-in. diam. graphite electrodes are used and the furnace is

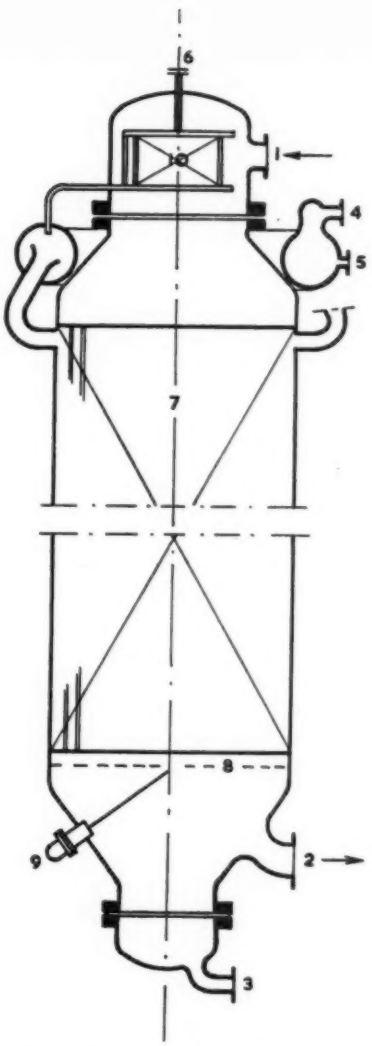

Fig. 2. Arge reactor, showing: (1) *gas inlet;* (2) *gas outlet;* (3) *product outlet;* (4) *steam outlet;* (5) *feed-water inlet;* (6) *heating steam inlet;* (7) *tube bundle;* (8) *catalyst support grid;* (9) *grid release device; and* (10) *steam heater.*

rated as 400 kVA when operating from a 3300-volt, 3-phase, 50-cycle supply. The furnace walls are lined by a build-up of catalyst that has frozen against the cooled walls. The electrodes are positioned automatically by a balanced beam voltage-current type regulator. When the charge is sufficiently molten, the furnace is tapped into ingot moulds on wheels. The temperature of the catalyst on discharge from the furnace is about 2800°F.

Size Reduction

As the catalyst solidifies and cools, it passes through a crystal transformation which causes it to break up its slab into smaller pieces. These pieces, when cool enough, are further broken with a hammer and are fed to a gyratory crusher which produces a material of size 100% $-\frac{1}{4}$-in. mesh. This crushed material is transferred by bucket conveyor to the final grinder feed hopper. The final grinding is carried out with forged and tempered steel balls of varying diameter, in a ball mill. There is an air classification system, the air passing through two

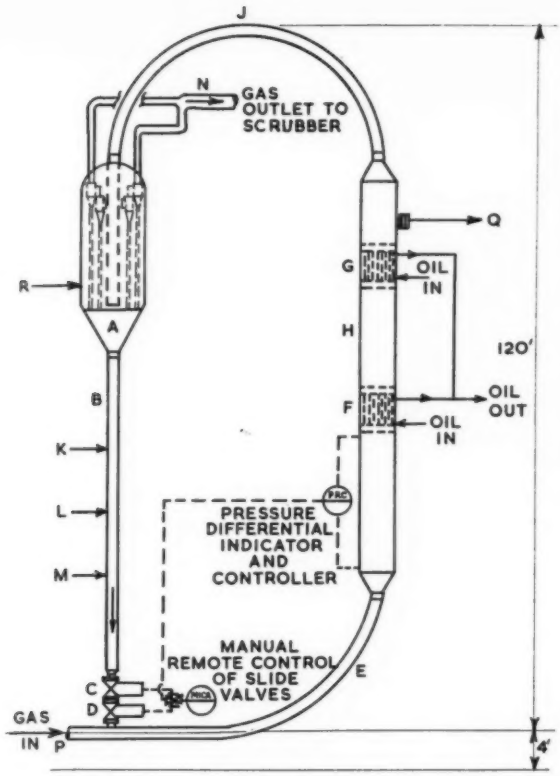

Fig. 3. Kellogg circulating catalyst synthesis reactor, showing: (A) hopper; (B) standpipe; (C and D) catalyst slide valves; (E) catalyst riser; (F) bottom reactor cooler; (G) upper reactor cooler; (H) reaction section; (J) goose neck; (K, L and M) aeration points: (N) gas outlet; (P) gas inlet; (Q) equilibrium catalyst out; and (R) fresh catalyst make-up.

cyclones in series before being discharged to atmosphere. The product of the ball mill is the optimum size for the final catalyst, and this powder is transferred by air to the unreduced catalyst storage drum. Reduction of the catalyst takes place under pressure and at an elevated temperature by circulation of hot hydrogen through the fixed fluidised-bed reduction reactor.

The fines of the catalyst are retained in the reactor by a set of metallic filter units. The reactor effluent gas flows through three of these units, while the fourth is being blown back to remove accumulated catalyst. Unheated recycle gas from the compressor is used for this blowing operation. The switching of these filters is done automatically through a time cycle controller. Water vapour produced during the reduction is condensed and separated from the hydrogen. The hydrogen is then recompressed, heated in a furnace and recycled to the reduction reactor.

Reduction of a batch of catalyst to metallic iron (plus promoter) generally takes 48-50 hours. At the end of this period, the reduced catalyst, which, when properly aerated with nitrogen or hydrogen, acts as a viscous liquid, is transferred to the fresh catalyst storage drum in the synthesis-unit using inert gas or hydrogen. It is stored at about 40 psig under inert gas or hydrogen until it is required in the synthesis reactor.

Synthesis. In the synthesis section of the plant there are two units, A and B. Each unit operates independently of the other, but in an identical manner. This duplication of equipment exists throughout the stages from synthesis reactor to the separation of gas and liquid products. The product gas and oil streams from both units are combined for processing. The equipment for storage and transfer of make-up catalyst is also used for both units. Only one reactor (see Fig. 3) will be described. The catalyst inventory of the reactor is initially contained in the catalyst settling-and-storage hopper *A*. The catalyst in the standpipe *B* is kept aerated through *K*, *L* and *M*, to enable it to flow freely through slide valves *C* and *D*. The slide valves operate with *C* normally wide open and *D* more or less open, depending on the amount of catalyst it is desired to admit to the reactor. This valve can be automatically controlled on the pressure drop—directly proportional to catalyst density—in the lower part of the reactor, below cooler *F*, or it can be controlled manually by remote operation.

Gas feed to the reactor consists of fresh feed from the gas re-forming unit and internal recycle gas in a ratio of about 1:2. (Internal recycle gas is product gas from the reactor from which all condensable products have been removed.) The combined feed has an approximate composition of:

N_2	10%
H_2	40%
CO	8%
CO_2	14%
C_nH_m	27%
H_2O	1%
	100%

A portion of the fresh feed gas is preheated in a gas-fired furnace so that the temperature of the combined feed is about 400°F. The total design feed volume is 250,000 Nm^3/hr ($INm^3=37.97$ s. cu. ft). This does not include the gas used for aeration of the standpipe. The feed gas is admitted through *P* and meets the catalyst dropping through *D*. It is estimated that the catalyst circulation through the reactor is in excess of 4000 tons an hour. (1 ton=2000 lb.) The gas-catalyst mixture travels through the 42-in. D-riser *E* at a rate of 25-30ft/sec. and enters the base of the reactor. Catalyst loading in the transfer line is about 8-10 lb. catalyst for each cu. ft of gas at feed temperature and pressure. Reaction takes place at a pressure of 250-300 psig.

Control of Reaction

The reaction is highly exothermic and begins immediately upon contact of feed gas and catalyst. The heat of reaction increases the temperature of the catalyst-gas mixture as it travels through the transfer line and reactor. The rate of reaction and its completeness can be governed to some extent by control of the catalyst loading, i.e., the quantity of catalyst/cu. ft of gas or, in other words, the available reaction surface. Increased reaction increases the temperature and, thus, the rate of reaction. Careful control of temperature and catalyst loading is necessary. To maintain the temperature of the gas-catalyst mixture at the desired level—between 550°F and 650°F—two reactor coolers (*F* and *G*) are supplied. The gas-catalyst mixture passes up through the cooler tubes and cooling oil flows round the tubes. Cooling oil rates are adjusted to each cooler to maintain the required gas temperatures. The hot oil from the reactor coolers is sent to a flash drum operating at about 50 psig and flows from here, by gravity, through a steam generator where 200 psig dry saturated steam is produced. The total heat removed from the gas-catalyst stream must equal the excess heat of reaction. However, this heat may be removed in either the top or bottom cooler to maintain reactor temperatures as nearly uniform as possible. At full rates the steam raised is in

excess of 30,000 lb./hr for each reactor.

The catalyst plus reacted gas passes through the gooseneck *J* through a pipe to the surface of the catalyst bed. Here the gas rises and, by gravity, the cataylst starts to drop. The gas divides into two streams, each of which passes, through two cyclones in series, to exit lines. The entrained catalyst drops out on the way through the cyclones and is led via dip legs to the catalyst bed. A normal loss of catalyst with the gas stream is less than two tons a day. On a catalyst circulation of 5000 tons an hr this is $\frac{2}{5000 \times 24} \times 100 = 0.0015\%$. This, considering the small particle size of catalyst, illustrates the efficiency of the disentrainment equipment. This loss, plus the catalyst removed from the hopper, is replaced with fresh catalyst from the storage drum. The replenishment is transferred with the aid of H.P. nitrogen.

Treatment of Gas

The effluent gas streams from the cyclones join in a common main and enter a scrubber tower, the functions of which are to cool the gas stream somewhat and to remove the heavy oil and entrained catalyst. These ends are accomplished by contacting the vapour feed with a stream of oil-catalyst slurry, so that the vapour is cooled and the heavy oil is condensed out. Catalyst in the feed is picked up by the oil and a clean gas is left to pass overhead for further separation of products. The tower has two bubble-cap trays in the upper part with baffles in the middle section and an internal cone, above which a liquid level is maintained in the lower part. Slurry oil is taken from the liquid above the cone, pumped through coolers, and returned to the tower for scrubbing of the vapour stream. A stream sparger is installed in the liquid above the internal cone to maintain agitation of the slurry and strip out light ends. The slurry not withdrawn for recirculation passes down through a line at the centre of the internal cone, to the catalyst-settling section at the bottom of the tower. In this section the catalyst settles from the heavy oil and is removed from the bottom as a slurry. The heavy oil, called decanted oil, from which the catalyst has settled, rises to the top of the section and is removed for further treatment. The slurry of catalyst and heavy oil is referred to by the evocative title of "gunk" and is discharged into drums for disposal or later recovery.

The tower top temperature is about 290°F at 235 psig, which is normally high enough to prevent condensation of water. However, the lower tray is built with a seal pot to trap water. This seal pot is piped to the outside of the tower so that accumulated water may be drained to the sewer. Vapours leaving the tower first pass through mist extractors. These vapours contain non-condensable gases, light hydrocarbons, other chemicals and water. The flow is split into two streams which enter the condensers where the cooling medium is steam condensate being pre-heated before use in steam raising. From these two condensers the gas-liquid mixture is passed to a bank of four coolers where cooling water removes the heat. The outlet streams pass at a temperature of about 100°F to a separator drum.

Inhibition of Acids

As a certain amount of fatty acids are produced in the synthesis, all surfaces in contact with condensed products are protected by inhibition of the acids. This has proved very effective and mild-steel equipment is used throughout. In the separator drum the non-condensable gas separates from the liquid and passes through a mist separator. A portion of this gas passes to a knock-out drum, from where the recycle gas compressors take suction. These compressors are driven by steam turbines at about 7000 rpm. This recycle gas is called internal recycle gas and, after boosting, is added to the reactor feed gas. The liquid products in the feed to the separator drum accumulate in the bottom of the drum. The liquid separates into an upper layer of light hydrocarbons and a lower layer of water which contains chemicals. Part of the oil layer is withdrawn from the side of the drum and pumped back to the scrubber tower top as reflux. The level of the interface between oil and water layers is automatically controlled by throttling the flow of water from the bottom of the drum. The water layer is sent to another section for further processing. The excess or net product oil is removed to the oil wash tower, which is common to both reactors.

Gases from the product separator drums which are not used as recycle are washed in a tower containing fourteen bubble-cap trays to remove traces of acid. The gas enters below the bottom tray and ascends through a descending aqueous solution of carbonate which enters at the fifth tray from the top. Process water is admitted to the top tray and scrubs out traces of carbonate from the rising gas. The water is removed from the tower at the fourth tray. Water and carbonate effluents join to enter a degassing drum before it passes through a gooseneck to the sewer. The gas from the degassing drum goes to flare. The products gas from the gas wash tower passes to another section, where it is further treated to remove its higher hydrocarbons. The gas, after removal of the hydrocarbons, is referred to as "external recycle gas". The light oil from the separator drum contains oxygenated chemicals in addition to the hydrocarbons. The water-soluble chemicals are removed from the oil in a Raschig-ring-packed tower by counter-current water washing. The oil is the dispersed phase in this tower and, after washing, is passed to the product recovery section. The wash water is added to the aqueous stream from the separator drums prior to treatment for recovery of the chemicals. The liquid production designed for is 4000 BPSD, i.e., 140,000 Imperial gallons a day, including polymer gasolene produced in the catalytic-polymerisation section.

More Water From Reservoirs

SUCCESSFUL TESTS (just completed) of C.S.I.R.O.'s Mansfield process on a large reservoir at Broken Hill, Australia, will mean that the world's reservoirs can provide more water. Over the past fourteen weeks, evaporation from the Stephen's Creek reservoir has been reduced by 37%. More than 200 million gallons of water, which is equivalent to six weeks' summer consumption in Broken Hill, has been saved. From this experiment, the estimated cost of the water saved is 1d. 1000 gallons. Under less favourable conditions, the cost of saving water will be greater, but it should not exceed 6d. 1000 gallons.

C.S.I.R.O. and the Broken Hill Water Board started a joint research programme in December, 1955, under the supervision of the inventor of the process, Mr. W. W. Mansfield, of C.S.I.R.O.'s Division of Industrial Chemistry. The object was to modify the process to work on large areas of water. The raft method, which is being used extensively now on small areas of water, is uneconomic on large areas because of difficulties associated with the action of wind and wave. However, by December, 1956, an alternative method had been found which produced a satisfactory film of cetyl alcohol by feeding on to the surface of the reservoir a solution of cetyl alcohol in a solvent. With this new method, a satisfactory film has been maintained for more than three months, in spite of exceptionally high wind velocities. About 1ft of evaporation has been saved over an average area of 930 acres.

THE APPLICATION OF AUTOMATIC PROCESS CONTROL TO CHEMICAL ENGINEERING

Part 2: Pre-control and Deviation Control

by N. J. HASSETT, Ph.D., M.I.Chem.E.

SYMBOLS USED

t = time;
dt = an infinitesimal change in t;
T = temperature;
$\triangle T$ = a temperature change or difference, usually in the one material;
θ = a temperature difference inducing heat flow;
$\triangle\theta$ = a finite change in θ; and
$d\theta$ = an infinitesimal change in θ.

The use of θ to indicate input or output signal is consistent with this nomenclature.

IN the previous article it was shown how disturbances in a process stage could be correlated in terms of a common unit, preferably the unit in which the process condition is defined and measured. In the following article the resultant of all the involuntary disturbances will be termed the disturbance, and the applied correcting disturbance, the correction. The resultant of the disturbance and correction is then the input signal to the process stage.

There are two distinct modes of controlling a process stage. The first seeks to eliminate deviation by maintaining zero net disturbance without reference to the measured variable and any deviation. This implies a close control on inputs and sometimes on outputs. As an example, the acetic-acid dilution process discussed in the previous article will be considered. To dilute 90% acid to 5% requires the addition of 17 parts of water to one part of concentrated acid. If the individual flows are indicated by, say, rotameters, then this mode of control would require that an operator should manipulate a valve on the water line to maintain a flow of water 17 times as large as that of the acid. This mode of control is referred to in the literature as open-loop control, but the term pre-control is preferable.

The second mode of control derives from the measured condition. The deviation from the desired value is the signal for operation of the control valve. In the example chosen, a rise in acidity of the product above the desired value of 5% would require the operator to open the water valve further, and conversely. This mode of control is usually known as closed-loop or feed-back control by analogy with electronic circuits, but the term deviation-control will be used in this series of articles.

Each of these modes of control has evident disadvantages. The first mode takes no account of possible variation in strong acid concentration or of temperature changes which would affect flow-rate readings. Although it would be possible to monitor the control to allow for one or more of these possibilities, it would be preferable to employ the second mode. For some types of process stage deviation control is not practicable. In general, these are where the product is not susceptible to rapid assessment; for instance, in the continuous blending of powder-mixtures or pastes, and pre-control must be used.

Deviation control has the disadvantage that corrective action cannot be initiated until the disturbance has reached the measuring instrument and some deviation has already occurred. The design of a control system is concerned with applying correction fast enough to prevent the deviation exceeding some predetermined value, or persisting longer than some given period, or both.

Process Stages

The wide range of types of process stage can be broadly classified as follows: Stages of

(1) Large capacity and large tolerance.
(2) Large capacity and small tolerance.
(3) Small capacity and large tolerance.
(4) Small capacity and small tolerance.
(5) Moderate capacity and moderate tolerance.

Each type of process stage responds best to a particular control system, but specific and local considerations will govern the final choice. Automatic control seeks to imitate what a skilled operator would do to maintain a process

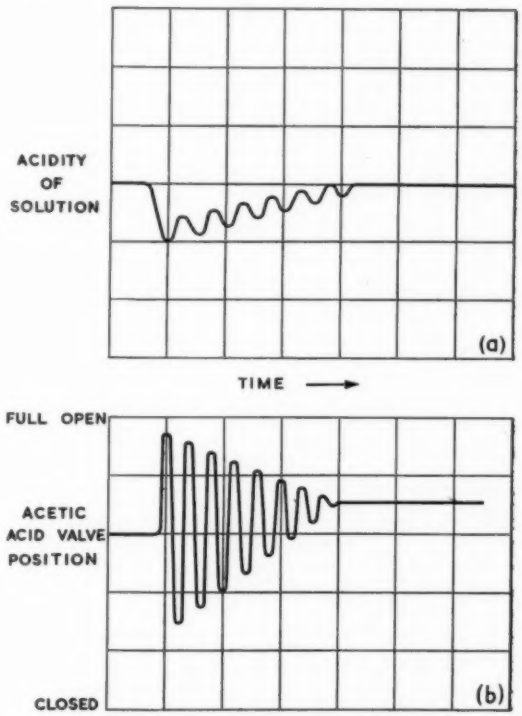

Fig. 1. Diagram showing the response of the valve controlling the supply of acetic acid to dilution process when the acid concentration falls suddenly.

stage within the desired limits of operation, and satisfactory results can sometimes be attained by widely different control methods. Thus type 1 is exemplified by a large reservoir or supply tank with an ample feed main. The operator has the option of continuous feed with occasional rate adjustment or of filling to the maximum permissible level, shutting off the feed and waiting until the level approaches the permitted minimum level before reopening the valve.

Type 2 could be the holding section of a pasteurisation unit or bottom-product control in a rectifying column. Continuous control with quick reaction is necessary. The operator will probably react not only to the magnitude of any deviation from the desired temperature, but to the rate of change. Large capacitance means slow response.

Type 3 might be a degreasing unit presenting little difficulty, and type 4 a stage in a continuous nitrator system or a flash pasteurisation unit, presenting a more difficult problem. Pre-control can be regarded as a process stage of very small capacitance.

Deviation Control

In designing a control system, the demands first must be defined clearly. These are:

(1) The desired condition-control point.

(2) The maximum permitted deviation.

(3) Any time factor connected with the deviation—undesirability of oscillation, etc.

Since detection of some deviation is necessary before control can be initiated, and out-of-balance can increase while control action is building up, it is essential that the detecting element shall be sensible to changes in measured variable far smaller than the maximum permitted deviation, or tolerance. Correct instrumentation is, of course, integral with process control, but, apart from consideration of first- and second-order response and general features, instrumentation as such will not be treated in this series.

The Response Curve

The manner in which a process stage responds to a disturbance is of prime importance in control. The most difficult type of disturbance to deal with is a step change of the maximum magnitude likely to occur in the system. If the control arrangements can cope with this and keep the deviation within the acceptable bounds, then they can cope with any variation from the step disturbance.

When control is applied, the correction usually oscillates. This oscillating correction is superimposed upon the disturbance so that, after a short initial period, a step disturbance develops into a sinusoidal input signal. The reason for this follows from a consideration of how control action operates. In the acetic acid dilution process, suppose the strong acid supply is suddenly changed to one of 80% concentration. The product begins to dilute towards an uncorrected equilibrium concentration of about 4.5%. If the control system has a sensibility of about 0.05% acidity, counteraction will commence when the acidity has fallen to 4.95%. By the time the control action begins to catch up with the disturbance, the acidity may have fallen further to, say, 4.8%. Control action now catches up and overtakes and there is a swing in the reverse direction. This repeats until the system settles down to a compromise equilibrium (except in the case of on-off control where the oscillation is sustained) (see Figs. 1a and 1b). Control design is concerned with reducing or eliminating this oscillation where undesirable.

An essential step in analysing control action is to study the uncontrolled response of a process stage, and this will be shown to be analogous to the response of a measuring instrument. In so far as the response of measuring instruments is also an important feature in process control, the response of a typical instrument will first be examined, and then compared with that of a process stage.

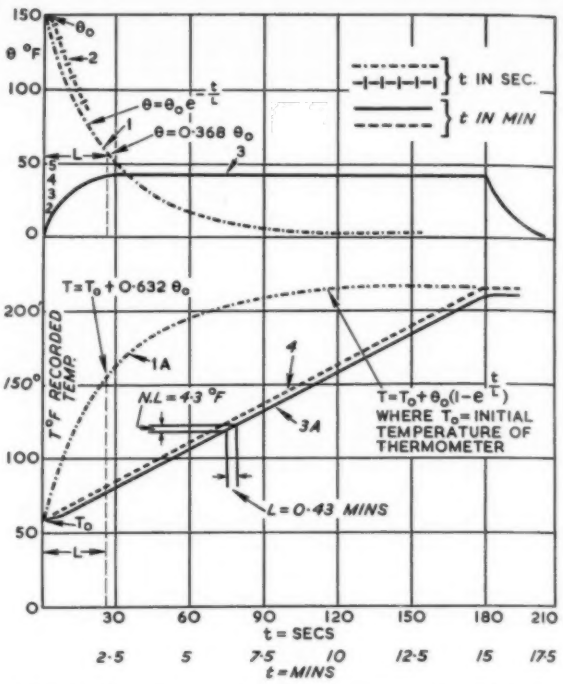

Fig. 2. Upper graph shows lag in temperature when a thermometer is suddenly placed in boiling water. The lower graph shows the temperature lag when the liquid, in which the thermometer is immersed, is heated at a constant rate to boiling point.

If a thin-walled mercury thermometer is suddenly immersed in hot water, the reading roughly follows an exponential or logarithmic curve with time, as would be expected from the following reasoning. If the effective heating area is A and the overall heat-transfer coefficient U, the heat transferred to the bulb in an infinitesimal time period dt is given by $dq = U\,A\,\theta\,dt$, where θ is the average temperature difference between the bulb and water during that period. The rise in temperature of the bulb and indicated by the thermometer is given by $dT = dq/C$, where C is the heat capacitance of the bulb. The rise in temperature of the bulb results in a corresponding decrease in temperature difference between bulb and water, since the temperature of the latter is constant, so that $d\theta = -dT$.

Summarising we have:

$$dq = U\,A\,\theta\,dt = C\,dT$$

whence
$$dT = \frac{U\,A}{C}\,\theta\,dt \qquad \ldots.(1)$$

$$d\theta = -dT \qquad \ldots.(2)$$

and
$$dt = \frac{-C}{A\,U}\frac{d\theta}{\theta} - L\frac{d\theta}{\theta} \qquad \ldots.(3)$$

where the group $\frac{C}{A\,U}$ is conveniently designated by L.

Integrating this equation from zero time when the temperature difference $=\theta_0$ gives

$$\log_e\left(\frac{\theta}{\theta_0}\right) = -\frac{t}{L} \qquad \ldots.(4)$$

$$\text{or } \theta = \theta_0 e^{-t/L} \qquad \ldots.(5)$$

where $e = 2.72$, the base of natural logarithms.

(This equation appears in the literature as $\theta_2 = \theta_1(1-e^{-t/L})$ where θ is measured from the original thermometer reading. In our case θ is the temperature difference.)

Equation 4 can be rewritten as

$$t = 2.3\ L \log_{10}\left(\frac{\theta_0}{\theta}\right) \qquad \ldots.(4a)$$

Example 5

A thin-walled mercury thermometer at 62°F is suddenly dipped into boiling water at 212°F. After 10 seconds it registers 110°F. How long will it be before it registers 157°, 210°, 211.5°, 211.9°, and 212°F?

The data enable the response factor L to be found from Equation (4a), which can then be used to find the required times. Rearranging Equation (4a).

$$L = \frac{t}{2.3 \log_{10}\left(\frac{\theta_0}{\theta}\right)} \qquad \ldots.(6)$$

$$= \frac{10}{2.3 \log_{10}\left(\frac{212-62}{212-110}\right)} = 26 \text{ seconds.}$$

The remainder of the computation can conveniently be tabulated.

Registered temperature, °F.	θ °F	$\frac{\theta_0}{\theta}$	$\log_{10}\left(\frac{\theta_0}{\theta}\right)$	$t=2.3L \log_{10}\left(\frac{\theta_0}{\theta}\right)$
62	150	1	0	0
110	102	1.47	0.17	10
157	55	2.72	0.43	26
210	2	75	1.9	114
211.5	0.5	300	2.5	150
211.9	0.1	1500	3.2	200
212	0	∞	∞	∞

These results are plotted as curves 1 and 1A, Fig. 2.

It will be noted that L is a factor which directly indicates the speed of response of the thermometer. It is known as the time-constant and is dimensional in time. Equation (4) shows that at a time L from the application of the step change, the temperature difference θ will have fallen to a value given by

$$\theta = \theta_0.e^{-1}, \qquad \ldots.(7)$$

$$= \frac{\theta_0}{e} = \frac{\theta_0}{2.72} = 0.368\ \theta_0.$$

The time constant of a thermometer can then be read directly from an experimental temperature time curve, noting where θ has reduced to 0.368 θ_0.

The simplifying assumption has been made in this derivation that the thermometer bulb is essentially a heat capacitance plus a surface resistance to heat transfer. The effect of the glass wall has been ignored. This assumption may be justified for a thin-walled thermometer, but would not be so for a thick-walled or sheathed instrument, as will be shown later. The actual curve would probably be more of the form shown in curve 2 of Fig. 2.

Response to a Ramp Change

Suppose now the same thermometer is immersed in water at room temperature and the water to be heated at a constant rate. The registered temperature of the thermometer will increase in accordance with Equation (2), but in the same short time the temperature of the water will increase by $N\ dt$ where N is the heating rate. The change in θ will then be:

$$d\theta = N\ dt - dT \qquad \ldots.(8)$$

and substituting for dT from Equation (1)

$$= N\ dt - \frac{A\ U}{C}\theta\ dt$$

$$= N\ dt - \frac{\theta}{L}\ dt \qquad \ldots.(9)$$

$$\text{or } \frac{d\theta}{\left(N - \theta\right)} = dt \qquad \ldots.(9a)$$

Integrating as before from zero time when $\theta = \theta_0$

$$t = L \log_e\left(\frac{N-\theta_0/L}{N-\theta/L}\right) \qquad \ldots.(10)$$

which can be written as

$$N-\theta/L = (N-\theta_0/L)e^{-t/L}$$

$$\text{or } \theta = N\ L - L(N - \theta_0/L)e^{-t/L} \qquad \ldots.(11)$$

The values of $e^{-t/L}$ for different t/L ratios are as follows:

t/L	...	0.1,	0.5,	1,	2,	3,	4,	5
$e^{-t/L}$	...	0.9,	0.6,	0.37,	0.14,	0.05,	0.02,	0.007

It will be seen that when t/L *is* 3 or over, the final term in Equation (11) becomes small and $\theta = N\ L$. In other words, the recorded temperature then lags at a constant difference from the true temperature.

Example 6

The thermometer referred to in example 5 is placed in water at room temperature (62°F) and the water is heated at the rate of 10°F per minute. What are the recorded temperatures at the end of ¼ minute, ½ minute, 1, 5, 10, 15 and 20 minutes?

At the end of 15 minutes the water will be boiling at 212°F, and will then remain at that temperature. Equations (10) and (11) will hold up to that time, when Equations (4) and (4a) will take over, with zero values as at the change-over.

Working in minutes, L = 26 seconds = 0.43 minute.

$$\theta_0 = 0$$

$$\theta = N\ L - L\ (N - \theta_0/L)e^{-t/L}$$

$$= 10 \times 0.43 - 0.43\ (10 - 0)e^{-t/L}$$

$$= 4.3\ (1 - e^{-t/L})$$

Tabulating:

t	t/L	$e^{-t/L}$	$(1-e^{t/L})$	θ, °F	Temp. of water, °F	Recorded temp., °F
0.25	0.58	0.55	0.45	1.9	64.5	62.6
0.50	1.15	0.32	0.68	2.9	67	64.1
1	2.3	0.10	0.9	3.9	72	68.1
5	11.6	negligible	1.0	4.3	112	107.7
10	23	„	1.0	4.3	162	157.7
15	35	„	1.0	4.3	212	207.7

At the end of 15 minutes θ = 4.3 and becomes θ_0 for Equation (5). At the end of a further 5 minutes $\theta = \theta_0 e^{-t/L} = 4.3e^{-5/0.43}$ = effectively zero; i.e. recorded temperature is 212°F.

It will be noted that when the time t exceeds five, the time constant L, the thermometer readings lags behind the water temperature by a constant amount, and actually indicates the water temperature at a time L preceding the reading. The results are plotted as curves 3 and 3A on Fig. 2. The temperature of the water is shown as a dotted curve (4) and the time and temperature intervals, L and $N\ L$ respectively, are indicated on the curves.

TRAINING CHEMICAL ENGINEERS

A symposium on chemical engineering education, organised by the Institution of Chemical Engineers, was held in Birmingham recently. Abstracts of selected papers are published below

Requirements of Industry

The Petroleum Industry

by F. Mayo

THE OIL-REFINING industry in this country has been characterised by the remarkable growth which has taken place since the war, and the industry is still expanding. With the exception of atomic energy, the industry requires and uses a higher proportion of scientists and engineers among its employees than any other industry, and of its scientists and engineers, a high proportion of chemical engineers is required. The industry shares the general concern over the country's shortage of scientists and technical people, and particular concern is felt about the output of chemical engineers.

The desired proportion of chemical engineers out of the total intake of scientists and technologists will probably vary somewhat from place to place, but the figures for Fawley will be significant. If we had a free choice, we would like to recruit about 52% chemical engineers out of the total technologist and scientist intake. What are we getting? Out of the forty most recent qualified recruits, we have taken on only eight men who took chemical engineering for their final degree. A further eight men had supplemented their degrees (mostly chemistry) with a chemical engineering diploma or with some study or experience of chemical engineering. With training and experience, many of these non-chemical engineering recruits will ultimately, of course, become first-class chemical engineers, but the process is wasteful of manpower and costly. The position is regarded as serious.

We require flexible employees. As a company, we attach considerable importance to training people by rotation through a number of different jobs. For instance, we move men through the main divisions of our technical department; plant technical service; planning and economics; process design and we move them from the technical department to supervisory posts operating the plants themselves, and perhaps back again to the technical department. We believe that this movement, if not carried to excess, is a tremendous help in building up a balanced team. The ideal process engineer needs many qualities, not least of which are imagination and appreciation of another man's job and how it affects his own; one way in which we can foster these qualities is by giving a man as wide an experience as possible. Men who are trained as chemical engineers in our experience are easier to rotate than pure scientists (or for that matter mechanical engineers): hence again our emphasis on an increased output of chemical engineers by the universities and technical colleges.

How much importance do we attach to the different classes of degree? Our experience does not suggest any clear-cut lessons. It is important that we should attach neither greater nor lesser significance to a first- or second-class honours or a pass degree than the degree itself indicates. The indicated qualities may, or may not, go hand in hand with an ability to deal with actual situations, which is, of course, of prime importance. The first-class honours man with a balanced and acceptable personality is the most desirable recruit who will soon climb the promotion ladder.

The Chemical Plant Industry

by J. P. V. Woollam and J. D. McFarlane

ONE OF the fundamental qualities desirable in all engineers is cost-consciousness. It is realised that it is difficult to give concrete instruction in this subject in an educational establishment, owing, amongst other things, to the comparatively small amount of information which is available in the British literature. It is not necessary for the average chemical engineer to be able to estimate the cost of a unit to a degree of accuracy necessary for a tender, but the ability to work out rough prices for the purposes of budgeting figures and economic balances is unlikely to go unrewarded for long.

A chemical engineer must be able to express himself and to communicate his ideas with clarity. Much has been written in the past on this subject, but this is a feature which cannot be over-emphasised. Another point which does not seem to have received sufficient emphasis in the past is the ability to receive other people's ideas and understand exactly what is in their minds and to be able to phrase questions to obtain the information needed. During training, he should have had a reasonable amount of experience in drawing-office practice. Plant operating experience should be acquired as soon as possible, as it is only in this way that a young chemical engineer will be made to realise many of the difficulties that occur in chemical plants and how to get over them in practice. For a chemical engineering student desirous of entering chemical plant industry, vacation training in these aspects of the profession is very useful but he should also endeavour to gain some experience of general heavy engineering workshop practice. There are many qualities which are required in all branches of chemical engineering, such as versatility, dependability, compatibility with colleagues and initiative. These are qualities which, at the undergraduate level, are best developed by taking part in the social and athletic sides of university life. A chemical engineer should always be alert and on the lookout for new ideas and processes which may come from reading journals, attending meetings and discussions with people in other walks of life and it is for the employer to see that these opportunities are exploited to the fullest possible extent. It is also the duty of the employer to ensure that, to the limits of his ability, every chemical engineer does have time to think and do work on new ideas which may not be of immediate utility.

The design engineer must have a broad knowledge of chemical engineering and must have a versatile mind, capable of envisaging a number of schemes to attain the desired end.

The contract engineer, however, should have a broader knowledge of engineering than the design engineer need possess. He must be able to suggest to the design engineer possibilities of revision of the design to suit some features not envisaged when the plant was originally designed, and

he must be able to hold his own against experts in many fields. His most important characteristic is probably ability to lead. The commissioning engineer probably comes into more intimate and prolonged contact with the client than any other member of the organisation, often in circumstances leading to differences of opinion which can result in long discussions before agreement is reached. He meets with workmen and process labourers more than most of the other members of the organisation, and he must be capable of explanations in an elementary, if not academically correct, manner.

Discussion

DR. HOBLYN complained that the role of the chemical engineer as a project co-ordinator had been underestimated in the paper on the chemical industry. Further, nothing had been said regarding the training of a chemical engineer for small firms. It was suggested that the position about cost-consciousness would be improved if industry released cost data on a scale comparable to that practised by U.S. firms. DR. KLINKENBERG, however, felt that students could be made cost-conscious without knowledge of absolute costs.

PROF. F. MORTON recommended as a means of helping students to gain practical experience that industry should lend teachers to the universities. He mentioned as an example the loan by Simon-Carves of two of their staff to the Manchester College of Technology.

The suggestion by one contributor to the discussion, that the universities should produce only honours graduates, and that the chemical engineer had only a restricted role as liaison between chemist, inventor and mechanical engineer, designer and constructor, did not find support. DR. W. S. NORMAN pointed out that if industry were to look askance at the pass degree, then it would lead to universities cramming students into honours courses to the detriment of both students and industry.

Methods of Training

Full-time Undergraduate Training

by F. H. Garner, O.B.E.

A FEATURE of the development of chemical engineering courses in this country is that a number of university degree courses in various technologies based on chemical engineering have now been changed to chemical engineering and, in general, it is considered that specialised courses in various technologies are best brought into the university curricula as post-graduate courses. Whilst there is a general agreement on the type of training required in the field of chemical engineering, there is some divergence in different universities as regards the content of the courses. Similarly, there are gradual changes in the content of the course at any one university year by year, since research is active in the basic principles as, for example, in showing the essential unity of the unit operations and in the development of similarities and differences between momentum, heat and mass transfer, which constitute such a large part of the basic principles.

The chief difference between different university courses is the point at which chemical engineering proper is introduced and there is much to be said for its introduction at as early a stage as possible, since it serves as a means of showing that all the pure science and other engineering subjects included in the course can be considered as branches of chemical engineering. The chemical engineering content of the course or that part of the course studied in the chemical engineering department must be considered as flowing from the earlier courses. It will include thermodynamics and reaction kinetics, the unit operations treated not as a series of separate operations but considered as a whole with a common method of approach to the mechanism of mass transfer, and with application to specific processes. Finally, chemical engineering processes and equipment must be studied with special reference to instrumentation and control. The analogy between momentum, heat transfer and mass transfer will play an important part, and, in general, all three must be considered together. There are also specific applications which can well be treated as part of the basic teaching (such as the fuel industries, including coal and petroleum and the chemical industries), because chemical engineering principles are of maximum interest to the student when illustrated practically.

Since the field of the chemical engineer is the development of processes and the design of plants in which chemical and physical processes are carried out, the types of chemical engineering plant are studied with reference to momentum, heat and mass transfer and to properties of materials, including corrosion. Practical acquaintance with the equipment in this respect is necessary. This can be partly met by work experience during the vacation, which has the additional advantage of emphasising the importance of human relations as with management and labour at an early stage in training; it also serves to stress the importance of works organisation regarding safety, legal and trade-union requirements. However, works experience during the vacation should be considered as an extension of practical work in the chemical engineering department.

Training by Private Study

by G. U. Hopton

THE THREE ways in which a student can train by private study are by correspondence course, by private lessons, and entirely on his own. If the student attempts to teach himself, he is undertaking a very difficult task. It is difficult because he lacks the guidance of a teacher, guidance which helps the student to choose what to read, which interprets the difficult passages, and, above all, which corrects the student's mistakes. The benefits of a teacher are obtained in varying degree in the two other methods of private study, namely, private lessons and correspondence courses. In all cases, however, training by private study should not be attempted unless the student is engaged in work of a chemical engineering nature where he can profit from the advice of a qualified chemical engineer, and obtain the experience which is necessary in applying theory to practice. Only in exceptional cases should a student choose to train by private study; every effort should be made to attend a formal course of study at one of the many educational establishments where chemical engineering is taught.

Discussion

PROF. F. MORTON expressed doubt about the value of diploma courses, because it was now impossible to bring a graduate in mechanical engineering or chemistry to the required standard in a single year. At least two years were required for the conversion. He considered that more attention should be paid to statistical methods. PROF. E. S. SELLERS agreed with Prof. Morton on the diploma course, but PROF. M. B. DONALD stated that the diploma course enabled twice as many students to qualify as would be the case otherwise. It also helped the development of such subjects as biochemical engineering.

MR. TOLLEY deplored the tendency to regard non-university work as lower in standard than university work. He thought that the H.N.C. course had been in the formative stage long enough and that the qualification entitled its holders to become professional chemical engineers.

DR. J. R. TAILBY thought that courses were overloaded and that something should be shed to enable the students to spend more time on general university activities.

(To be continued.)

BURNING OF SULPHUR-BEARING MATERIALS FOR SULPHURIC ACID MANUFACTURE

PART 2*

This article describes the Herreshoff burner, flash roaster and the Flixborough burner, gives details of satisfactory operating conditions for them, and outlines processes for separating sulphur from hydrogen sulphide and acid sludge

IT has already been stated that the only things that are obnoxious about sulphur are its co-called bitumen content and the incombustible solids it contains, but these solids are rarely in excess of 0.5%. All the objections that can be made against this solid material in sulphur are magnified hundreds of times when one deals with the sulphides of heavy metals. These substances have the further disadvantage that they almost invariably contain other volatile constituents, which may poison the catalyst in the conversion stage or add unwanted impurities to the product sulphuric acid. It is a question of pure economics—certainly not of convenience—whether they are used at all for sulphuric acid manufacture. The commonest form of metallic sulphide used to produce sulphur dioxide is iron pyrites.

Herreshoff Burner

Before World War I this material was burnt in hand-fired kilns, the pyrites being in the form of lumps 2-3 in. in diameter. The utilisation of this size of ore created problems at the mines, as there was no ready market for the large quantities of fines being produced and this situation led to the designing of a mechanical burner to burn these fines. This type of burner is commonly called the Herreshoff burner. It consists of a number of hearths arranged in tiers, one above the other, with a vertical shaft through the centre of the burner to which is attached a series of rakes, one or two rakes serving each hearth. These rakes move the ore across the hearth, dropping it successively from hearth to hearth. This means the raw ore is fed on to the top hearth, which in some burners is open, and is only used to pre-dry the ore before feeding to the burning hearths.

The pyrites is fed on to the top or drying hearth by one of various mechanical devices. The body of the burner usually consists of a mild-steel shell with a brick lining, although some have been built of all-brick construction having steel supporting bands at each hearth level. The centre shaft can be cast-iron or mild steel, brick-lined. However, this latter is, in our experience, not to be recommended, as it is difficult to key the brick lining in such a way that it will remain *in situ* for any length of time. The rakes can be of either cast-iron or chrome steel. The centre shaft and arms are cooled by air which is blown into the bottom of the centre shaft, and exhausted to atmosphere at the top of the burner. Water cooling has been tried, but has proved to be unsatisfactory because of the difficulty of getting watertight joints. In our opinion, air is far more satisfactory.

Normal pyrites contains approximately 48% sulphur and will burn spontaneously in a furnace of this type without extraneous fuel. The primary air for combustion is admitted into the bottom hearth through adjustable air ports, the air travelling counter-current to the burning pyrites. Secondary air can be admitted through small air ports to any of the succeeding hearths. It is in the second and third hearths that 75% of the burning takes place, the succeeding hearths being necessary to achieve maximum combustion. The cinders, mainly ferric oxide containing 2-3% sulphur, leave the furnace via the bottom hearth, from whence they are disposed. The speed of rotation is of the order of $\frac{1}{4}$ r.p.m. An approximate capacity of this type of furnace is about 30-40lb. pyrites/24 hours/sq. ft hearth area.

The economics of sulphur dioxide manufactured from a Herreshoff burner are mainly dependent upon efficient roasting, and the efficiency of this is determined very largely by the following two points: (1) impurities in the ore; and (2) size grading of the ore.

Impurities such as copper, zinc and lead are detrimental, because they form sulphate during roasting and fix a proportionate amount of sulphur in the burnt ore residue.

Table 1 shows the theoretical roasting efficiency for pyrites. The size grading affects the burning efficiency. The sulphur is more readily burned out of the fine grades, because they present a larger surface area per unit weight to the combustion air than do the coarser grades.

The size range which is likely to give the best burning conditions is that from $\frac{1}{32}$ to $\frac{1}{4}$ in. The reason for proposing a minimum size of $\frac{1}{32}$ in. is that very fine dust leads to high local temperatures in the burner, causing clinkering and also increasing the dust burden on the dust precipitators. Material larger than $\frac{1}{4}$ in. increases the sulphur losses in the burnt ore due to inefficient burning.

Flash Roaster

A more recent method of treating pyrites is known as the flash roaster process (see Fig. 10). As the name suggests, this is essentially a device for roasting pyrites

* Continued from *British Chemical Engineering*, 1957, **2**, 248.

TABLE 1

	Average	Per cent by weight: Maximum impurities	Per cent by weight: Minimum impurities
Sulphur	47.50	46.95	48.58
Zinc	2.00	3.00	1.32
Copper	0.74	0.83	0.44
Lead	0.56	0.55	0.72
Arsenics ...	0.48	0.42	0.50
Maximum theoretical roasting efficiency ...	97.3	96.4	98.2
Unavailable sulphur contact of burnt ore ...	1.7	2.5	1.2

rapidly, only a small quantity being present at any one time. Among its advantages are good roasting efficiency, possibility of waste-heat recovery, no moving parts in the roaster, and greater flexibility and ease of control than a mechanical furnace.

The roaster consists of a void cylindrical vessel with a cone bottom, the whole being lined with 14 in. of firebrick. The upper portion is surrounded by a jacket, the air from which is drawn off by the primary air fan, thus reclaiming heat. The pyrites is fed by a variable-speed screw into the delivery of this fan and the air stream carries it to the roaster top; extra primary air, if required, is conveyed by another pipe. The air solidus pyrites mixture enters the roaster centrally at the top surrounded by a stream of recirculated gas at 300-350°C which is caused to rotate by tangential entry and by vanes in the stream; the resultant effect is that particles of pyrites describe an expanding helix before reaching the base and should then be burned out. Secondary air to strip the ore is admitted tangentially at the roaster base and the hot SO_2 withdrawn tangentially at the top.

Operation. The first item of importance is the grinding of the pyrites; in order to grind satisfactorily and obtain a free-flowing feed, it is necessary to dry to less than 0.1% moisture. Grinding in the ball mill is to 86-92% through 100 B.S.S.; coarser grinding leads to cinder falls in extreme cases, and in any event more sulphur is retained in the cinders than the normal 1-3%. Too fine a grind, on the other hand, leads to excessive cinder load on later sections of the plant. The gas strength should be as high as practicable—of the order of 12% SO_2—as this inhibits formation of unwanted SO_3. When working at 8-9% SO_2, some 4-5% of the total sulphur is converted to SO_3, but this can be reduced to 1-2% by working at a high concentration of SO_2.

The firing zone, or highest temperature region, should be at the bottom of the roaster just above the roaster cone. Indications of temperatures are given by thermocouples in the gas channel to the boiler and at the top, middle and bottom of the roaster. When using Cyprus pyrites, for example, these would read 940°C, 950°C, 960°C and 970°C respectively. If the highest temperature is elsewhere, it is probable that a cinder build-up on the walls is in progress which will eventually come away as a cinder fall. Additional primary air will "drive the heat down" and the general level of temperature is controlled by recirculation.

The greatest attention must be paid to cleanliness of the turbine head of the roaster, as blockage of the vanes

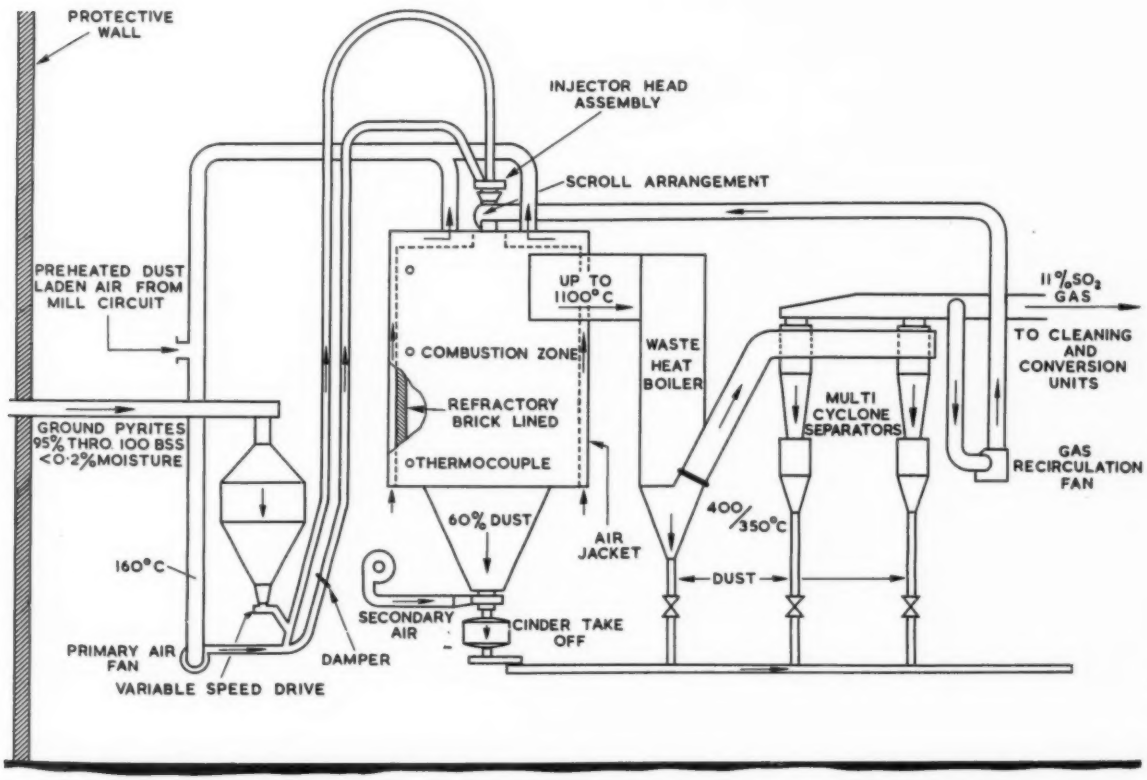

Fig. 10. Line diagram of the flash roaster, a device for roasting pyrites rapidly.

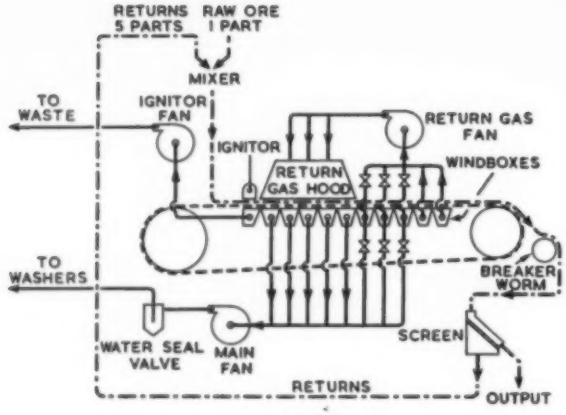

Fig. 11. Dwight-Lloyd burner.

or excessive wear will cause deflection of the firing cone to the wall, followed by major cinder falls. In this connection, when re-starting after a stoppage, it is of great importance to have the recirculation fan running at fair speed, even if its damper is closed. This prevents air and pyrites short-circuiting and firing in the injection head and recirculating main, which would later lead to blockage.

Temperature evolution is such that something like 2,000 lb. of steam at 375 psi and 650°F can be made per ton of acid. The boiler is, however, much more of a problem than on a sulphur plant, owing to soot blowing. As only 25% of the cinder is retained in the roaster, an efficient dust-removal plant is necessary.

Economics of Flash Roasting. Based on comparable sizes, a flash roaster plant has double the capital cost of a sulphur plant and, therefore, the depreciation per ton of acid is doubled. Labour cost is also high, being about four times that on a brimstone unit. Repair costs are likewise high, due largely to abrasion in the grinding and cinder-handling sections. In general, flash roasting is not attractive economically as opposed to sulphur burning, and if pyrites is to be used, then a turbulent-layer process would seem much more advantageous.

Other Sulphides

It is not proposed to discuss in any detail the production of sulphur dioxide from any other metal blends, because their treatment is entirely determined by the process requirements involved in producing the metal, and it might be said that the original processes devised to make sulphuric acid from the sulphur dioxide developed from the treatment of these blends was in many ways a convenient and economic way of satisfying the Alkali Inspector! We will content ourselves to say that a favourable process in these metal industries is to use the Dwight-Lloyd burner (see Fig. 11). The process consists of diluting down the raw ore feed, possibly in the ratio of 1 part to 5 parts of burnt ore. These are fed on to a metal conveyor belt, are ignited initially by a producer-gas flame and are then conveyed along the belt over suction boxes which withdraw the sulphurous gases, leaving the burnt ore to pass over the breaker worm and advance to a screen. The process is exothermic; once started, it is self-supporting.

Another substance which is in effect an iron sulphide is spent oxide, which is produced in one process for removing hydrogen sulphide from coal gas. In this process, hydrogen sulphide passes over bog iron ore, with which the gas reacts. The resultant mass may contain as much as 50% sulphur after it has been aerated and partially consists of iron oxide and free sulphur. It is possible to extract this sulphur with a solvent such as toluene.

Another method which is gaining favour is a process which has been developed at Nitrogen Fertilisers Ltd., Flixborough, and is in the form of a kiln (see Fig. 12). This has the great advantage that the iron oxide produced by the burning process is in a form suitable for re-use to absorb hydrogen sulphide. Other processes (due to their high temperatures) produce a form of oxide which is unreactive. The kiln is fitted with a heat-resisting alloy-steel tube down its centre. The spent oxide is fed in on to a refractory brick-lined kiln and is heated by the outgoing gases in the centre tube. The residue drops from the end of the kiln and is taken away. The centre tube also provides a secondary combustion zone for burning distilled tarry matter. The process of heat transfer from the inner tube of spent oxide is assisted by fitting lifting boxes which rain down the solid on to the tube as the kiln rotates. The gases contain about 6.5% SO_2. A certain amount of dust

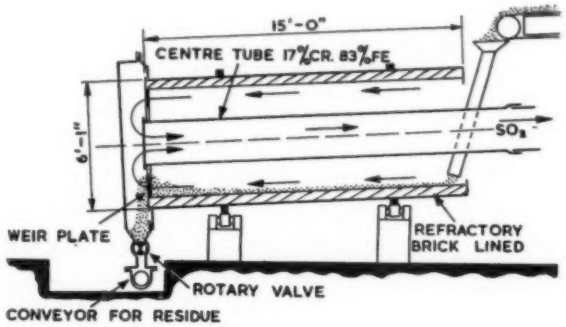

Fig. 12. Flixborough spent-oxide burner.

is carried over, amounting to about 5.5%, to the feed. The burner can be shut-down very quickly and can be on full load in 12 hours.

Hydrogen Sulphide

A source of sulphur which at the moment cannot be considered very important, and again is rather a question of making an embarrassment a source of revenue, is that of hydrogen sulphide. This can be derived from coal-gas liquor which usually contains 0.3-0.4% H_2S. It is derived from the ammoniacal liquor by evaporation; when ammonia, carbon dioxide and H_2S is evolved, the ammonia is absorbed in sulphuric acid and the H_2S and carbon dioxide gases are sent to a burner. A typical composition of this gas is 11% H_2S, 16% CO_2, 14.5% oxygen and 58.5% nitrogen.

A more important form of H_2S derives from petroleum. Crude petroleum can contain up to 5% sulphur, although these higher sulphur-containing oils are usually American. The Middle East oils have the following typical sulphur contents: Kuwait 2.5%; Iraq 1.9%; and Arabia 1.5%. A straight oil distillation disengages about 10% of the sulphur present, and catalyst cracking about 50%; specified processes for removing the sulphur, such as the Shell hydro desulphurisation and the Unifining processes, disengage up to 95% of the sulphur, but these processes require an outside source of hydrogen.

In the United Kingdom with a cracking capacity (March 1955) of 5.3 million tons per annum, the sulphur which could be recovered is about 45,000 tons a year.

In these processes the hydrogen sulphide is usually absorbed. The most efficient to date is said to be the "Thylox" process, which uses an aqueous solution of sodium thioarsenate, but the sulphur produced is rather

Type of Furnace	Ore	Size	Lb. S burnt per 24 hours	
			per sq. ft grade area	per cu. ft furnace volume
Hand furnaces	Pyrites	about 25 mm	6-8	—
Mechanical roasting furnaces (25 tons capacity)	Pyrites	about 6 mm	15-20 (1)	8
Rotary furnaces (70 tons)	Pyrites	about 6 mm	20 (2)	7.5
Dwight-Lloyd	Zinc concentrates 7% S. Sinter feed		35	

Table 2—Comparison of performance of various roasting furnaces.

Notes: (1) Related to total hearth area. (2) Related to inner diameter of cylindrical portion.

impure and the most widely used is the "Girbotol" process, which uses an aqueous amine solution, ethanolamine and similar substances; the H_2S is removed from this solution by heat.

Having obtained the hydrogen sulphide, it is possible to burn it all to SO_2 and H_2S, or to burn only one-third to sulphur dioxide and produce sulphur from the following interaction:

$$2H_2S+SO_2=2H_2O=3S.$$

The oil companies tend to favour this sulphur-producing process, as the former leads to a wet-gas process (water being present with the SO_2). We shall first describe the process used for burning H_2S.

After concentrating the hydrogen sulphide gas (gases below 2% H_2S cannot be used) and possibly accumulating it in a gas-holder (fitted with diversion for H_2S to flare in case the upper limits of the holder are exceeded and with a shut-off for the supply below a certain limit), it is usually pumped by a Rootes Connersville blower to the burner at a pressure of about 4 psig. The air can enter with the H_2S gas in the same gun; more usually it enters separately. In one plant the gas is led through a water seal to a pressure-release valve (which also shuts-off if the pressures fall below a critical value) and passes through a metal-gauze filter to enter the side of a horizontal mild-steel, brick-lined cylinder through a simple tubular gun which impinges on a perforated plate. Air is separately blown into the cylinder, tangentially away from the perforated plate. The gas is then passed counter-current to the incoming air through a mild-steel tubular heat exchanger, which is, so to speak, part of the burner body. This arrangement was considered a weakness of the scheme, as burner radiation fell upon the tube plate and considerably reduced efficiency, as well as causing a certain amount of burning of the mild steel. A better arrangement may be to have the heat-exchanger portion at right angles to the burner, or even as a distinct unit.

For the sulphur-producing process, the principal feature is the use of a catalyst to speed up the reaction between hydrogen sulphide and sulphur dioxide at a temperature low enough to prevent oxidation of the hydrogen sulphide. This can be achieved at about 220°C with such catalysts as activated carbon, bauxite, silica gel and alumina; glass and brick are poor catalysts. Iron retards, while iron oxide and copper practically stop the action. The favourite catalyst is bauxite, which can have a life of 8-20 years. Fig. 13 illustrates the process.

The hydrogen sulphide and air enter the burner and about 29% of the reaction takes place at this stage, the sulphur being condensed by the waste-heat boiler and running out to the pit. The gases then pass at about 300°C into a further heat exchanger and are cooled to about 140°C. Another 22% of sulphur is recovered at this stage. The gases are then reheated at 225°C in a burner, burning either fuel gas or H_2S with air, in which case the air/gas mixture is controlled to avoid upsetting the H_2S/air ratio in the main stream. The H_2S gas enters a kiln supported on a firebrick floor which divides the chamber in halves. The gases enter the kiln at the top, and the lower section has a sloping floor for sulphur drainage. The top surface of the catalyst is protected with broken firebrick to remove soot and to absorb violent temperature fluctuations. About 1.5% of the sulphur is removed from the kiln-seal pot. The gases are further cooled and a further 19% of the sulphur removed. Recovery at this stage is 71.5%.

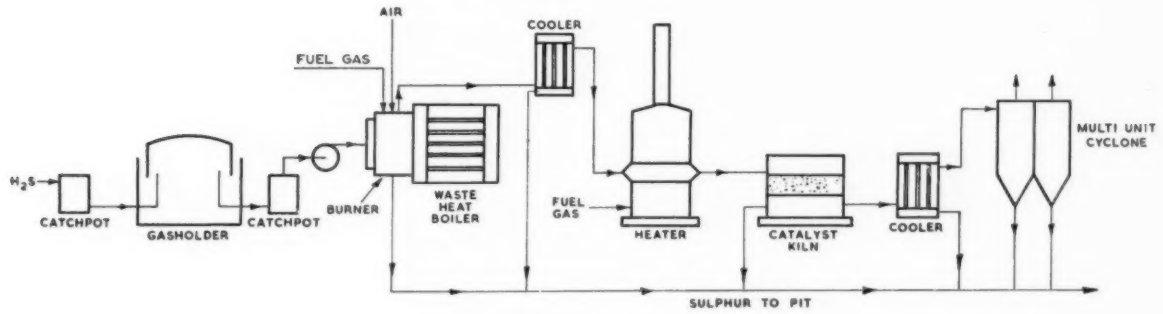

Fig. 13. Diagram illustrating the sulphur-producing process.

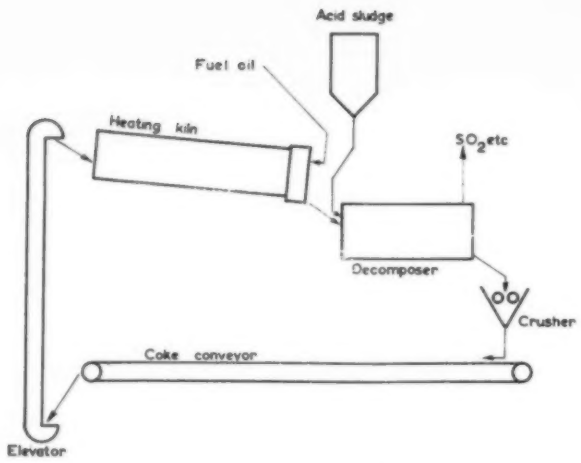

Fig. 14. SO_2 from acid sludge.

Multi-cylone units in parallel are used to remove the sulphur mist and a further 8% of sulphur is recovered. The gas is reheated and passed through an exactly similar series of processes, catalyst-bed cooler and multi-cyclones, when a further 14% of sulphur is recovered. The total conversion is now 96-97%. The sulphur obtained has a purity higher than 99.9%. The molten liquid from underground pits is pumped to liquid storage tanks or to boxes, where it solidifies and is broken down by pneumatic hammers. Explosion discs guard the equipment, which is usually of mild steel.

Acid Sludge

Another sulphur-bearing material in the oil industry is acid sludge. Britain's petroleum industry uses about 60,000 tons of sulphuric acid a year in its treatment of its various oil products; that is equivalent to about 20,000 tons of sulphur, which reappears as acid sludge which varies in sulphuric acid content from, say, 5-90%, although the usual concentration is about 50-60%. The sludge can be a mobile liquid of an extremely viscous material which solidifies with age. The disposal of this sludge acid has been a problem with refineries for many years and the following methods of treating it have been adopted:

(1) Burning the sludge directly as fuel, utilising the heat to generate steam.

(2) Hydrolising the sludge and recovering the fuel oil and dilute acid which is reconcentrated.

(3) Decomposing the sludge and recovering the sulphur dioxide.

It is the third method that concerns us. It is not suitable for acids rich in oil, though these can be blended off with the lighter sludges. There are two main variants of this method; one is a low-temperature method operating at about 300°C, and the other is a high-temperature process operating at about 1200°C.

Low-temperature Process

The sludge is stored in heated storage tanks so that it maintains a temperature of about 40°C, and the tanks are stirred. The pump is fed by the steam reciprocating pump and the lines are steam traced. The sludge is pumped to a burner fed with coke from a kiln. The rotary kiln is refractory-brick lined. The acid sludge drops on to the hot coke and the acid is decomposed into sulphurous gases and coke. The gases pass into the cleaning system and thence to the sulphuric-acid plant. The coke drops down into a crusher and is carried by conveyor to a coke bin. The coke then passes through a kiln heated with fuel oil to about 750°C, from which it drops back again into the decomposing kiln to receive sludge acid. In effect, the sludge acid is making its own coke, which, being heated, decomposes the acid (see Fig. 14).

High-temperature Process

The high-temperature process consists of spraying the spent acid by means of a spinning-cup into a brick-lined furnace, where it is decomposed at a temperature of 1100-1200°C to form sulphur dioxide, the hydrocarbons in the sludge furnishing the fuel. The hot gases leaving the decomposing furnace pass through a silicon-carbide tubular heat exchanger which pre-heats air entering the furnace.

Anhydrite

We will refer only briefly to this abundant indigenous source of sulphur. Calcium sulphate can be reduced to calcium sulphide with coal at about 800°C; in the presence of kaolin or certain acidic oxides, the sulphide will react with additional sulphate to produce sulphur dioxide and the corresponding calcium salt. By adding the right proportions of iron oxide, alumina, silica and lime, the latter becomes Portland cement, which then only requires grinding to be rendered marketable. The correct mixture of anyhydrite, kaolin, coal and coke is ground in ball mills and fed into a calciner heated by pulverised coal which is blown in at the discharge end. The calciner is lined with refractory brick and is water-cooled at the firing end. A maximum temperature of 1400°C is reached in the hottest zone, which is about 30 ft from the firing end. The clinker is fed through recuperators, ground and fed to hoppers and bagged as cement. The kiln gases, containing about 9% sulphur dioxide, are sent to the purification section.

Welsh Water Resources

THAT THE abundant water resources in Wales should be exploited for the industrial and economic benefit of that country is urged in a booklet just published by the Welsh Economic Development Council. Many of the figures on which the Council's statements are based are of wide interest. At present about 2000 million gallons of water a day are supplied by the water undertakings of England and Wales, it is pointed out. Of this total, Wales provides about 270 million gallons, some 140 million being supplied by Welsh authorities and some 130 million gallons obtained from Wales and supplied by English authorities to their consumers. The demand has been steadily increasing during the past 20 years, and it has been estimated that by 1970 the water undertakings will have to supply at least twice the amount of water required in 1938. This rapid increase in consumption is attributed largely to the "spectacular" rise of consumption by industry. The total surface-storage capacity of England and Wales is now in the region of 200,000 million gallons, of which approximately 60,000 million gallons is located in Wales. Sixty-three per cent of the reservoir capacity in Wales, some 38,000 million gallons, is owned by English authorities, and the remainder, some 22,000 million gallons, by the Welsh authorities. The capacity of England and Wales is equivalent to three months' supply of water for those dependent upon the reservoirs, but some areas have less than three months' supply and others have more.

TEDMAN SEPARATOR—ITS OPERATING PRINCIPLES

by D. TEDMAN*

THE basic principle of the Tedman separator can be shown by the following experiment. The apparatus used consists of a 2-in. diameter glass cylindrical vessel with glass cone ends and $\frac{1}{8}$-in. diameter apex orifices. The wall of the cylindrical portion is grooved to form two turns of a helix. Two tangential inlets are inserted, one in each helical turn, so that by feeding sand-slurry to one inlet the sand will follow the grooved wall to the second turn and will then travel round the cone wall to be discharged at the apex orifice (see Fig. 1a). If water is now allowed to flow through the jet connected to the second helical turn, the sand will cease travelling round to the second turn and cone wall and will appear on the other cone wall (see Fig. 1b). By reducing the water flow-rate the former condition is almost immediately re-established. By adjustment of the water flow, the sand flow can be divided so that a part is carried back to one cone end, while the balance travels in the opposite direction. By inserting an additional helical turn (with no inlet inserted) between the other two, these effects can be accomplished using less water at the water inlet. A consideration of the forces involved explains these phenomena. The force tending to drive a particle round the helix is a function of the centrifugal force. This, in turn, is a function of the slurry inlet-pressure and the frictional forces tending to reduce the angular velocity of the particle. The greater the retardation of the particle in its circular motion, the smaller is the boundary current required to reverse the axial component of its direction.

The boundary current acting along the wall from the higher to the lower inlet-velocities, and counter-current to the axial direction of the groove, increases with the inlet water pressure. The fact that the particle track-angle down the cone wall is independent of variations in the water pressure, when other conditions are the same, shows that there is a relationship between inlet pressure and the boundary-current strength. Thus, the water jet or inlet becomes more effective by providing intermediate stopped turns, so that less water is required to produce the same separation.

Another relationship exists between the water and slurry inlet-pressures. From experiment, the ratio of these two is found to be about the same for separations of the same-size cut or ratio of concentration.

* *Chemical and Mining Division of Vickerys Ltd.*

TABLE I.

Curve	Water supply flow rate, Gal./min.	Portion of feed to coarse, %
A	35	5
B	30	12
C	25	20
D	22	33
E	20	50
F	17	70
G	15	80

For a given separation the particle velocity along the inner wall, v_t, due to the component of centrifugal force in this direction, is equal to the boundary current V, and the particle has no axial motion. The approximate particle-velocity through the boundary current will then be given by Stokes Law with v_t substituted for g. The centrifugal force will be nearly proportional to the slurry inlet-pressure. Thus, for balance, the ratio of the water inlet-pressure to the slurry inlet-pressure will be approximately constant.

The boundary flow is independent of any variation in the sizes of the main axial discharge orifices. Thus one discharge orifice can be blocked and the particles will still continue to move towards the blocked end, building up in the cone until the vortex collapses and all the solids are discharged at the opposite end. This current can be generated along any shape of wall, helical, cylindrical or conical. With a conical wall it can be made to flow towards the apex or, with suitable location of jets, towards the widest diameter. It is not understood whether or not this current is due to frictional effects at the wall, and work is going on to investigate the matter further.

Another feature of this flow is its ability to move large particles, even as great as $\frac{1}{8}$-in. diameter, down the cone wall (with cone axis horizontal) to the apex discharge orifice. Particles of this size have a slow axial motion towards the apex and will become stationary axially if the included cone angle is too large.

In his article on the Tedman separator published in the May, 1957, issue, the author presented a group of curves (p. 246, Fig. 2) which illustrated the effect of water feed upon the separation of a closely sized, −30 mesh slurry feed at a solids rate of 80 lb/min. Table 1, given above, assists to clarify Fig. 2.

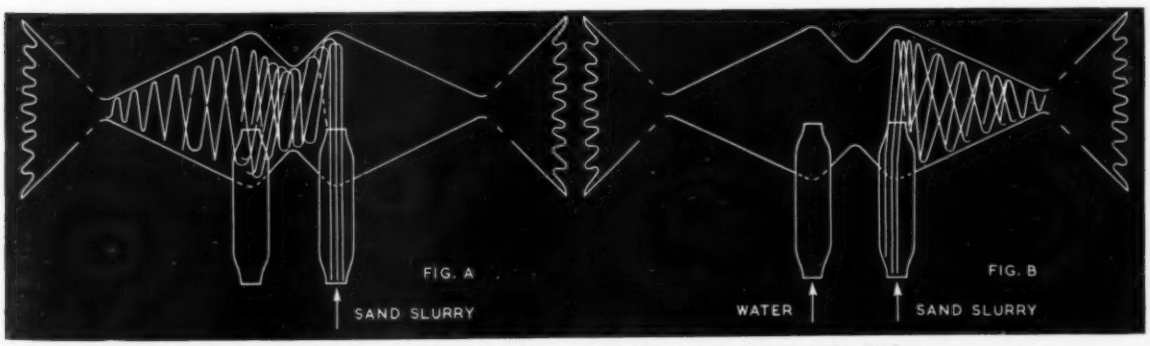

Fig. 1. Apparatus for demonstrating the basic principle of operation of the Tedman separator.

AMERICAN LETTER

Chemical and Metallurgical Engineering

EXTRACTIVE metallurgists are faced, in general, with three problems: first, to supply the world with ever-increasing annual tonnages of basic, strategic and rare metals; second, to meet more stringent specifications as to purity, high-temperature behaviour, stress and corrosion resistance; and third, and sometimes the greatest problem, to satisfy these demands from diminishing natural resources, or from alternative ores often lower in metal content and more difficult to process. The result of these challenges is that the distinction between ore processing, extractive metallurgy and chemical engineering is now fine. It is useful, therefore, to review briefly some of the major U.S. activities in the metallurgical field and to see where reciprocal benefits have arisen.

Perhaps iron may still be regarded as the most important metal—in 1956 120 million tons of its ore were consumed by U.S. smelters. Until recently about 80% of the nation's supply came from directly-mined sources in the Lake Superior region and the balance from deposits in the west and other areas of the country. Last year marked a significant change for 12 million tons came from the new Quebec-Labrador mines, 11 million tons from Venezuela and 4½ million tons from the newly-constructed taconite plants in the Lake Superior area. The taconite source is of great national importance and is expanding rapidly. A total capacity of some 13 million tons of concentrates is expected to be achieved by the end of 1957 and this may rise to 40 million or so by 1975 thus providing a substantial portion of the nation's needs.

The development of full-scale taconite mining and concentration has been a remarkable enterprise owing to the huge tonnages handled and the extremely hard, abrasive nature of the ore—about 600 Brinell, or harder than glass. One company, the Reserve Mining Co., at present concentrates over 36,000 tons of taconite each day and expects soon to double this rate. The process is a triumph of super-scale metallurgical and chemical engineering, and basically consists of grinding, cyclone-segregation, hydro-separation by thickening, followed by filtration. The de-watered pulp is sent to nodulising, or balling drums; then to coal-coating drums and pelletising equipment of the sintering type. The pellets are finally screened to a 2-in. size and are sent to a storage area of 1½ million tons capacity. This project cost nearly $200 million. This is but one of the taconite activities already built or planned. The Erie Mining Co. is completing a $300 million project that will produce nearly 8 million tons of pellets annually. A great, new industry has thus been born within the space of a few years.

At the present time, much work is being carried out on this direct reduction of iron ore in fluidiser-reactors, with the aim of eliminating blast furnaces, and it is possible that, during the next decade, chemical engineering may make a substantial contribution to the U.S. iron and steel industry by solving this problem on a large scale, using ores of medium grade.

The recent release by the Government of information concerning uranium has revealed that current national reserves are estimated to be about 60 million tons of ore, averaging 0.25 per cent U_3O_8. About two-thirds of these reserves lie in New Mexico, the balance being found in Utah, Colorado and other Western States. Ore production is at present about 3½ million tons per annum and may increase to 6 million tons annually by 1970, under normal circumstances. Current production of U_3O_8 from natural ores is about 6000 tons annually and twelve major plants are in operation for this purpose. No outstanding mining difficulties have had to be solved, as was the case with taconite, but economic extraction problems have been many. These have led to the development of the following three new large-scale techniques: column ion-exchange; resin-in-pulp exchange for ores of a slimy nature; and leaching and solvent extraction.

Large-scale trials are also being made with the process, using alkaline or carbonate solutions instead of the customary acid leaches.

Considerable work has also been carried out on the extraction of U_3O_8 from wet-process phosphoric acid, especially in Florida, where the uranium oxide content is about 200 mgm. per litre, compared to 90 mgm. per litre for acids made from other sources of rock. One interesting development has been the use of continuous centrifuges for performing a number of operations formerly carried out by more conventional methods, such as separation, extraction and mixing. Liquid/liquid solvent extraction using decyl alcohol derivatives and multi-compartment turbo-extractor columns has also been developed by at least one company for performing difficult extractions. The cost, to date, of the U.S. uranium development programme has been gigantic, even by American standards. A figure of $14 billion has been quoted, and this does not include the development and production of nuclear weapons.

Although the United States is plentifully supplied with most raw materials, the rapidly expanding titanium metal industry, at present, is based largely upon supplies of rutile ore from Australia. It is desirable, for strategic purposes alone, to develop alternative sources of rutile on the American continent and deposits are being investigated in Mexico, Canada, South Carolina and New York State. Another proposal might be to upgrade ilmenite, which would present yet another problem for metallurgical and chemical engineers to solve economically. At present, most of this metal is produced by the Kroll process, but sodium reduction, as pioneered by I.C.I. of Great Britain, is likely to become popular.

Several companies are actively investigating an electrolytic recovery process, using a fused salt such as potassium titanium fluoride, but precise details have not yet been revealed. There is no doubt, however, that the structural and corrosion-resistant properties of titanium are responsible for a phenomenal increase in demand. Production of sponge metal rose from 1000 tons in 1952 to about 15,000 tons in 1956 and this figure might even be doubled within the next year, if all currently planned units are brought into successful operation.

Although spectacular advances have not been recently reported for basic metals such as aluminium, nickel, manganese and zinc, steady progress has been made as regards minor developments in technology and output levels. Copper and some strategic metals such as tungsten, tin and antimony are said to be comparatively inactive at the present time, both as regards turnover and new developments; progress in the rare-metals field is extremely active by comparison. New techniques, such as zone-melting, and new applications for metals such as germanium, lithium and boron are being constantly developed.

BCE 1306 for further information

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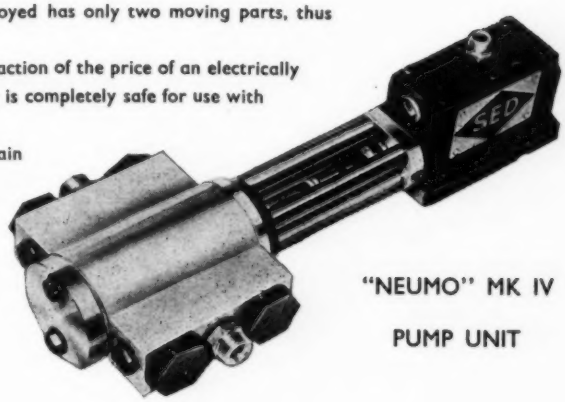

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FLUIDISATION VELOCITY — TURBULENT FLOW

The published data on fluidisation velocities have been critically reviewed by Johnson[1]. A mathematical analysis of his own experimental data led to the following equation for fluidising velocity in case of turbulent flow:

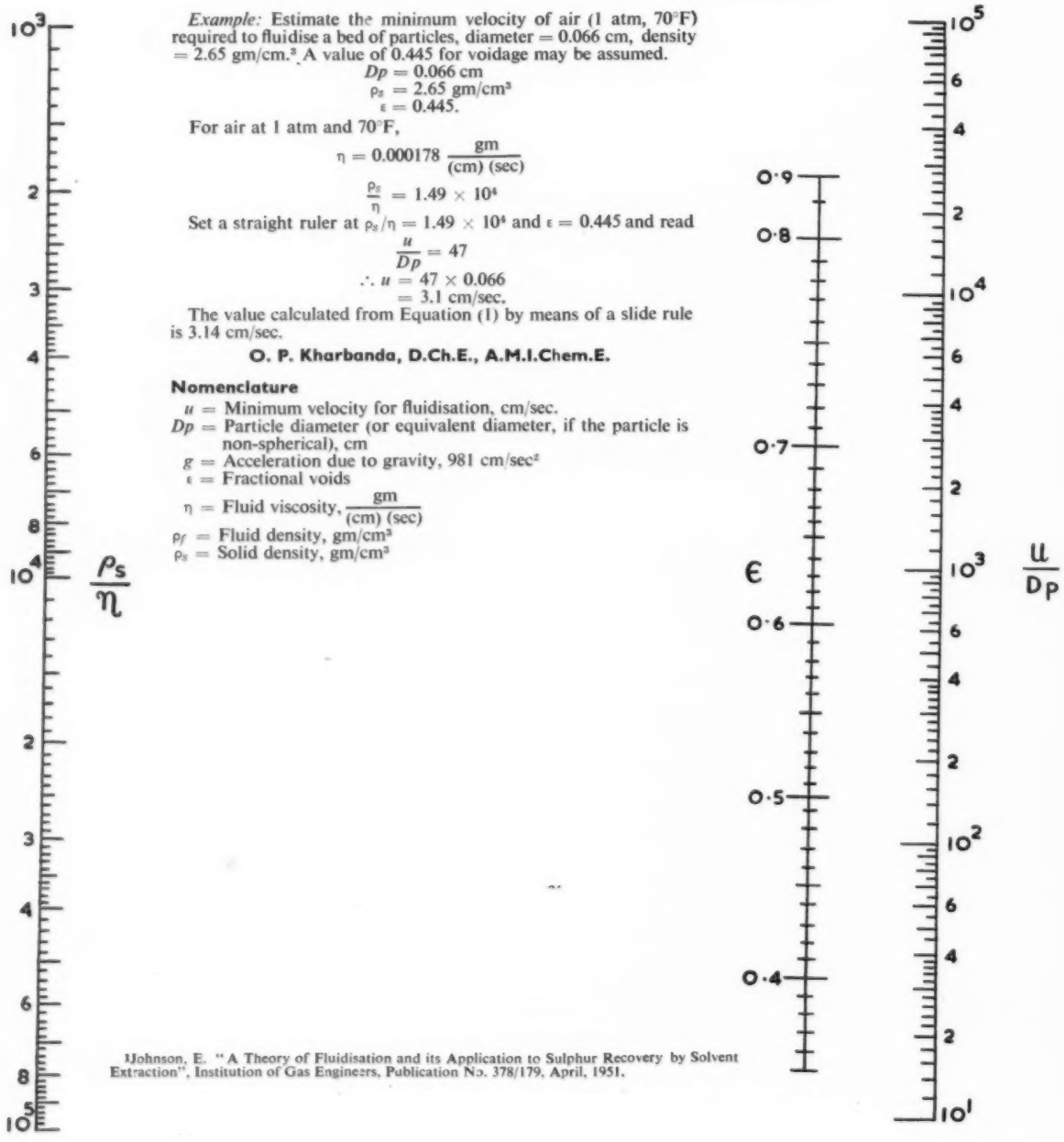
$$u = 0.171\, Dp \sqrt[3]{\frac{g^2\, \rho_g\, \varepsilon^6}{\eta\,(1-\varepsilon)\,\{1+0.5\,(1-\varepsilon)\}}}\ \left(\frac{\varepsilon}{1-\varepsilon}\right)^3 \qquad \ldots.(1)$$

The criterion for turbulent flow is that the value of the modified Reynolds Number

$$\frac{Dpu\,\{\varepsilon\,\rho_f + (1-\varepsilon)\,\rho_g\}}{\eta\,(1-\varepsilon)}\ 0.123\,\varepsilon^3$$

is greater than 2. In general, however, it can be said that turbulent flow prevails when a gas is used as the fluidising medium.

The accompanying nomogram is a simple solution of the otherwise cumbersome Equation (1).



Example: Estimate the minimum velocity of air (1 atm, 70°F) required to fluidise a bed of particles, diameter = 0.066 cm, density = 2.65 gm/cm.³ A value of 0.445 for voidage may be assumed.

$$Dp = 0.066 \text{ cm}$$
$$\rho_g = 2.65 \text{ gm/cm}^3$$
$$\varepsilon = 0.445.$$

For air at 1 atm and 70°F,

$$\eta = 0.000178\ \frac{\text{gm}}{(\text{cm})\,(\text{sec})}$$

$$\frac{\rho_g}{\eta} = 1.49 \times 10^4$$

Set a straight ruler at $\rho_g/\eta = 1.49 \times 10^4$ and $\varepsilon = 0.445$ and read

$$\frac{u}{Dp} = 47$$
$$\therefore u = 47 \times 0.066$$
$$= 3.1 \text{ cm/sec.}$$

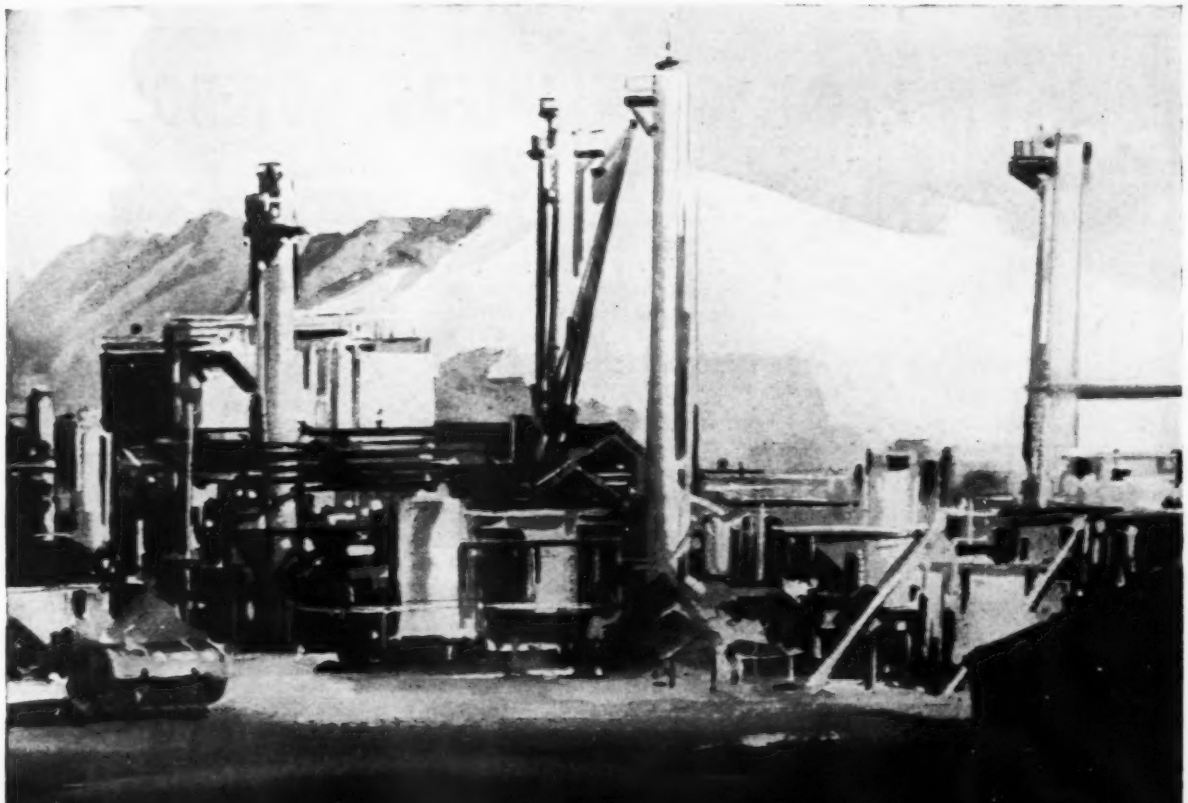
The value calculated from Equation (1) by means of a slide rule is 3.14 cm/sec.

O. P. Kharbanda, D.Ch.E., A.M.I.Chem.E.

Nomenclature

u = Minimum velocity for fluidisation, cm/sec.
Dp = Particle diameter (or equivalent diameter, if the particle is non-spherical), cm
g = Acceleration due to gravity, 981 cm/sec²
ε = Fractional voids
η = Fluid viscosity, $\frac{\text{gm}}{(\text{cm})\,(\text{sec})}$
ρ_f = Fluid density, gm/cm³
ρ_g = Solid density, gm/cm³

[1]Johnson, E. "A Theory of Fluidisation and its Application to Sulphur Recovery by Solvent Extraction", Institution of Gas Engineers, Publication No. 378/179, April, 1951.



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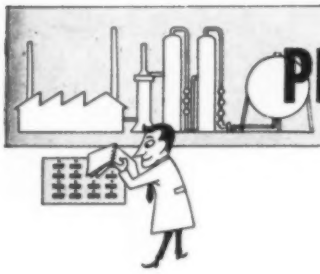
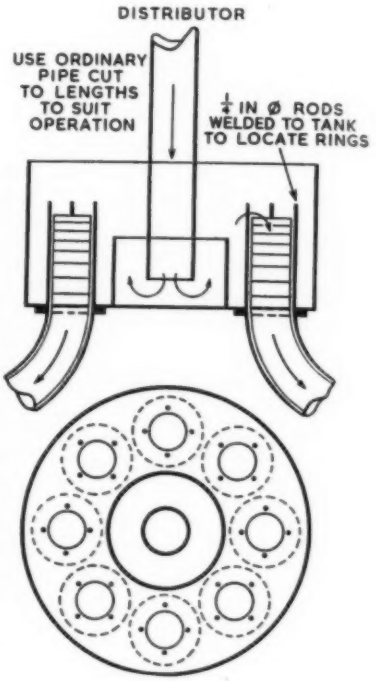


PROCESS ENGINEER'S NOTEBOOK

Simple Type of Distributor

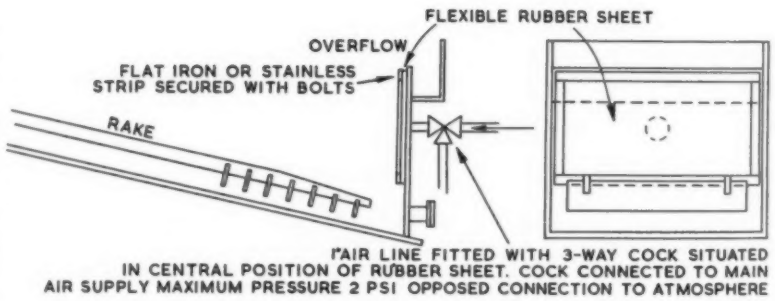


THE ACCOMPANYING SKETCH shows an inexpensive method of distributing high-density solid suspensions or viscous fluid to two or more feed points. The method of construction is simply to use a prefabricated steel tank or oil drum with sufficient depth to allow for maximum feed to all points. The circular baffle shown has to be welded or held in a central position in the tank and be deep enough to prevent splash or short circuiting. The feed line must be large enough to take the desired off-take capacity and enter at the centre of the baffle. It is advisable to enter the feed pipe to a point half-way down the baffle depth. Should the material being handled be abrasive, it would be advisable to use a rubber hose, and line the interior of the distributor with rubber.

The overflow rings are machined from standard steel pipe to various widths. It is advisable to machine four rings to, say, ½ in. or ¾ in. wide. The overflow rings are held in position by three ¼-in. rods welded to the bottom of the tank and at sufficient pitch to allow easy and speedy removal of rings. Outlets or "take offs" are either made of pipe or rubber hose welded or flange-bolted to the bottom of the distributor.

The distributor must be set level before operations begin. With equal and steady flow requirements to all feed points, the same amount of overflow rings would be placed at all outlet points. Should it be necessary to reduce the feed at one point, extra rings can be placed in position, until such time as no flow is required. With this method of distribution, samples can be taken at a central point for all feed lines.

Flexible Diaphragm Removes Build-up


FLEXIBLE RUBBER SHEET
OVERFLOW
FLAT IRON OR STAINLESS STRIP SECURED WITH BOLTS
RAKE
AIR LINE FITTED WITH 3-WAY COCK SITUATED IN CENTRAL POSITION OF RUBBER SHEET. COCK CONNECTED TO MAIN AIR SUPPLY MAXIMUM PRESSURE 2 PSI OPPOSED CONNECTION TO ATMOSPHERE

OFTEN IN CLASSIFICATION, when rake-type classifiers are used, a build-up of fine particles occurs which cements into a hard agglomerate and is difficult to remove (see sketch). When mechanical scrapers are used, the build-up drops into the bottom corner of the classifier and near the rakes, causing a blockage of the dump-valve connection and a possible overloading of the drive motor. A process operator finds it easier to "turn a valve" than to use a scraper on hard metallurgical or chemical solids build-up, especially when it is below the surface of a dense pulp which makes it impossible to observe the effect of his work. This operation also removes the danger of splashing from a deleterious slurry—the natural action of the operator being to lift his safety goggles to improve his vision.

In a conventional classification-grinding circuit where Linatex or flexible sheet rubber is used to line chutes, hoppers, and fines feeders, it is convenient to utilise this material, held in position with sheet-iron plate or stainless-steel strips bolted to the rake classifier back-plate. It is essential that the joints be air-tight and bolt-holes punched out cleanly to prevent the rubber tearing. A 1-in. air connection is welded to the centre of the back-plate, then a three-way cock is fitted to this with one branch connected to the compressed air supply, which should have a pressure gauge and bleed valve attached to reduce the applied pressure to a reasonable amount (2 to 4 psi).

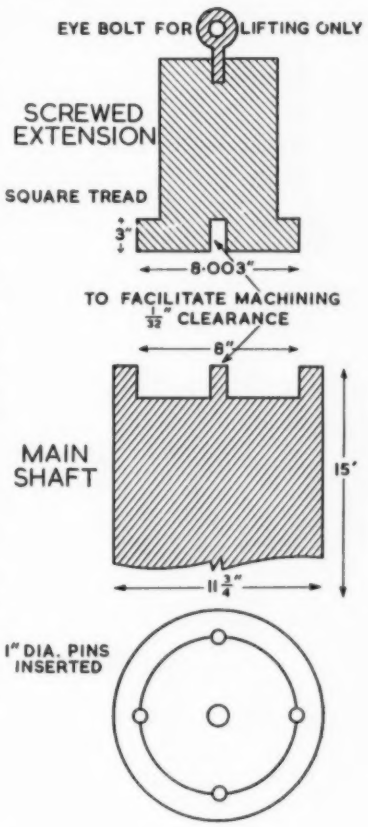
This principle has many applications in the chemical industry. For example, to remove the build-up produced at the surface slurry level and around the bottom discharge port of agitators, mixers and reaction vessels, provided that temperature conditions are not too severe. D.O.

Filtering Caustic Soda

THE PROCESSES employed for producing ammonia at coke oven plants involve the use of a 10% solution of caustic soda to wash the last traces of carbon dioxide out of the oven gas. In order to regenerate the caustic soda for further use, the resulting solution of sodium carbonate is then boiled with milk of lime and the precipitate of calcium carbonate which is formed is removed by filtration. This operation is carried out at a temperature of about 60° under suction in box filters. These are extremely severe filtration conditions and ceramic tiles had to be used for filtration. Each set cost about £60 and had a life of only three or four months. Now, however, nylon has been proved as a successful and cheaper medium. A cloth made up from a nylon fabric of about 20 oz./sq. yd. costs about £9 and has an average life of about six months. The annual replacement cost is therefore reduced to something like one-twelfth of the former figure. In addition to this substantial long-term economy, a nylon cloth is considerably easier to handle and can be fitted in a fraction of the time taken to bed in a new set of ceramic tiles.

Shrinking by Liquid Nitrogen

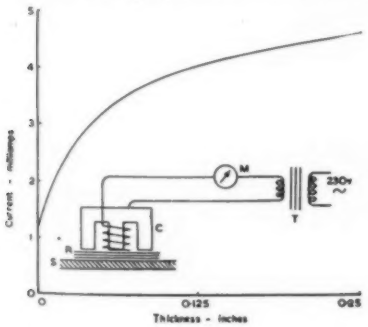
DURING THE FABRICATION of a capstan for a large ocean tanker, it was found necessary to make the main steel shaft in two units. The screwed extension, which has a square thread and which is used for raising or lowering the shaft to engage and disengage the clutch, had to be turned as a separate part. Initially, it was decided to expand the shaft so that the two parts could be joined. Due to varying thicknesses of metal, however, the expansion obtained would have been uneven, and liquid nitrogen was used to shrink the screwed extension so that it would fit into the main shaft. The shaft was 15 ft in length, with a diameter of $11\frac{1}{4}$ in., and a weight of $2\frac{1}{2}$ tons. It was positioned vertically in its main bearing and the extension was inserted at the top of the shaft. The extension was 8 in. in diameter and had been turned to give 0.003 in. interference. After immersion in liquid nitrogen for a period of 45 minutes, a micrometer reading showed that the part had shrunk to 7.995 in., which allowed 0.005 in. clearance. The extension was then lifted by overhead crane and dropped into the end of the shaft which was recessed 3 in. to receive it. Air vents had been cut in the extension, which dropped easily into place, and it was then drilled and pinned in position.



Survey Thickness Meter

A METER was recently required at short notice to survey the thickness of the bonded rubber lining of a mild-steel vessel. The accompanying circuit shows the instrument evolved to meet the situation and it was assembled and calibrated in a few hours. It has since been duplicated for a similar purpose. The method depends on the change in impedance of a coil linked with an iron circuit with a variable air gap.

In Fig. 1, T is a bell or filament transformer giving 4, 6 or 8 volts or any convenient low alternating voltage, and C is an ordinary smoothing choke (about 60 milliamps, size not critical) which should have E and I section stampings. The I section stampings are removed, leaving the coil on the E section as shown. The a.c. meter M can be either a portable multi-range instrument or a 10-milliamp moving coil meter connected across a small bridge rectifier (e.g., 24 volts, 75 milliamps).



The calibration graph was prepared by placing index cards (R) of known thickness on a piece of $\frac{1}{4}$-in. thick mild-steel sheet (S) as shown. The measuring head (choke) was subsequently moved slowly over the rubber lining and the rubber thickness read from the calibration graph, according to the meter reading. A typical calibration is shown in Fig. 1. The thickness can be read to better than 1/64 in. over the range 0 to over a $\frac{1}{4}$ in. The reading is almost independent of the thickness of the underlying mild-steel plate, provided this is greater than $\frac{1}{16}$ in. thick. It is almost independent of the curvature of the mild steel, provided the radius of curvature is greater than 6 in.

The instrument is naturally susceptible to mains voltage variations and, if used over a prolonged period, it is advisable to check the instrument at intervals on a portable thickness standard.

P. E. WATSON

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

Book Reviews

Chemical Engineering Kinetics

by J. M. Smith
McGraw-Hill, London, 402 pp., 60s.

THE understanding of catalysis and of chemical reactions accompanied by heat, momentum and mass transfer has now developed to the point at which it is possible to evolve sound design methods for various types of reactor. This is in fact the primary object of this book. Considerable space is given to design procedures with examples of their use in the design of different kinds of reactor. In using the term "design", the author refers to the principal dimensions of a reactor, such as its diameter and length, the nature of the catalyst contents and the composition of the reaction mixture at various parts of the reactor.

The author reaches his main objective in his fourth chapter, where he sets out to define the various kinds of reactor, such as batch and flow, homogeneous and heterogeneous reactors. In the chapter devoted to heat and mass transfer in reactors, the author illustrates his conclusions with a number of worked examples applied to such diverse operations as the evaporation of water from beds of solid desiccant and the effective thermal conductivity of a catalyst bed. Two methods are described for this latter case, the first is an approximation and the other a more rigorous method. In the chapter dealing with the design of gas solid reactors, examples are presented showing the design of a fixed-bed SO_2 converter and a very interesting example for a fluid-bed reactor for the conversion of carbon and carbon dioxide to carbon monoxide. The remaining chapters follow a similar pattern in the variety and number of worked examples given.

In spite of the undoubted utility of this book, there is some lack of balance. It is, for example, difficult to understand why so much space has been given to the subject of the statistical mechanics of chemical kinetics. Moreover, its treatment is hardly likely to lead to a deeper understanding of the subject and the examples chosen to illustrate it refer to elementary actions of a kind unlikely to be encountered in practice. However, there is little to complain of in the treatment of the method of dividing an overall reaction into its elementary components. Perhaps future editions will rectify the omission of any reference to the existence of an optimum temperature profile in an ideal tubular reactor for an exothermic reversible reaction. Despite these shortcomings, this book can be recommended to all those interested in chemical reactor design. J.O.S.M.

Chemical Process Economics in Practice

Edited by J. James Hur
Reinhold Publishing Corp., New York; Chapman & Hall, London; 1956, 115 pp., 32s.

THIS useful little book is the fourth in a series recording the "Experience in Industry" discussions sponsored by the Philadelphia-Wilmington section of the American Institute of Chemical Engineers and the School of Chemical Engineering of Pennsylvania University. This series was concentrated entirely on various phases of the conversion of engineering data into an economically useful form. Its nine contributors are recognised authorities on the economics of a number of processes.

One section of the book entitled "What Price the Chemical Product?", by F. Faxon Ogden, gives a very clear presentation of the preparation of balances that have to be done before a chemical product can be properly priced. The decreasing price pattern of a chemical as the scale of manufacture increases is explained lucidly. By means of a well-chosen example, he illustrates the fact that the highest price does not always yield the best return on investment.

John C. Martin deals with economic analysis. This paper sets out to compare various methods of analysing return on investment. The writer describes the "pay-out" method, the operator's method and the accounting method and other terms with commendable clarity.

The section by L. C. Knox on plant investment provides the reader with a comprehensive check list of fixed investment items, while other papers discuss the language of accountancy, methods of estimating overhead costs and ways and means of assessing and reporting plant-operating costs, including an account of various practices on depreciation.

Throughout the book the emphasis is on practical aspects of the subject, so that engineers and executives, especially those who are new to industry, will learn of the many ways in which the engineer and the accountant can work together. It has to be recognised, of course, that terminology and practices in the U.K. differ in some respects from those in the U.S.A., and with this proviso in mind this book is to be thoroughly recommended. J.M.S.

Instrument Technology: Volume II

by E. B. Jones

Butterworths Scientific Publications, London, 1956, 208 pp., 40s.

THIS is the second of a set of three volumes dealing with instrumentation. It deals with analysis instruments and methods of sampling, and includes some basic theory. It has been designed to cover the relevant part of the City and Guilds syllabus, but there is much in it that will be useful to works' chemists and chemical engineers. Such a work could not hope to do more than touch a fraction of the wide range of instruments on the market now available to industry, but a reasonable number have been described.

The chapter on sampling contains useful devices and tips for the plant chemist. In this connection, however, attention must be drawn to the statement (p. 3) referring to the use of concentrated hydrochloric acid for removing sulphur dioxide from gases from high sulphur-bearing fuels, before analysis; this derives from some recent research, but is not yet recommended for general works procedure. The chapter on density measurements could well have included the simple Westphal balance. A more serious omission is the lack of reference to effusion methods for measurement of gas density. Chapters on spectrochemical analysis, electrochemical measurements and thermal conductivity gas analysis include sufficient theory to explain the functioning of the instruments described. The final chapter on measurement of viscosity refers to laboratory methods, but describes only more advanced instruments; this, again, is a serious omission, from the viewpoint of City and Guilds candidates. On the whole, however, this is a useful work and to be recommended N.J.H.

Heat Treatment of Welded Constructions

British Welding Research Association, London, 1957, 28 pp., 5s.

THIS booklet indicates the main factors which should be considered in deciding whether to heat-treat a particular construction and contains recommendations based on accepted present-day practice and current code requirements. Information on stress-relief data for typical steels is provided, as well as a chapter on the general requirements for equipment, such as gas-fired furnaces and electric induction heating. The booklet concludes with a glossary of terms.

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Pilot Plants, Models and Scale-up Methods in Chemical Engineering

R. E. Johnstone and M. W. Thring

This is a study of the many ways in which model theory and empirical extensions of it can be used in the design of pilot plants or models and in the interpretation and scaling-up of experimental results. It is the first full-length book treatment of the subject, which is of interest to all chemical engineers concerned with plant or process design. For reference or supplementary reading it would be useful in university chemical engineering courses.
May-June 1957. *71s. 6d.*

Applied Mathematics in Chemical Engineering

H. S. Mickley, T. K. Sherwood and C. E. Reed

The second edition of the text by Sherwood and Reed has now been extensively revised and completely rewritten by Professor Mickley. It presents those methods of applied mathematics which are most helpful to the chemical engineer, in a form that can be readily used by both student and practising engineer. The mathematical background of the reader is presumed to be limited. The text begins with a discussion of the process of differentiation and proceeds step by step to more advanced topics, including the Laplace transform, orthogonal series, calculus of finite differences, partial differential equations and the numerical solution of both ordinary and partial differential equations.
May 1957 *second edition 67s. 6d.*

Epoxy Resins

A practical review of their chemistry and technology
H. L. Lee and Kris O. Neville

A comprehensive guide to the new field of epoxy resins, covering the chemistry of their preparation and their applications in industry. The available data on the resins are brought together, and information given on their synthesis and curing mechanisms, curing agents, and the various materials used as filler and modifiers, with emphasis on the engineering versatility, range and potentialities of the epoxies. In specific terms, the book discusses the industrial applications for the resin systems in laminates, adhesives, coatings, castings, foams, etc. Application techniques are discussed, handling characteristics are considered in detail, and the methods for characterising both cured and uncured resins are presented. On the basis of the extensive tabular and graphic data included, practical formulations are developed for a number of industrially valuable compounds.
August 1957. *Illustrated. About 45s.*

For more comprehensive details regarding these books please write to: Publicity Dept. (Book Division), McGraw-Hill Publishing Co. Ltd., McGraw-Hill House, London, E.C.4.

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World of Chemicals

U.S. Titanium Production

The production of titanium in the U.S.A. during 1956 was 14,100 short tons —nearly double that in the preceding year. Not all the metal produced was consumed, but the industry is going on with its expansion plans.

Swedish-East German Agreement

Sweden is to import potash and other chemicals from East Germany under the terms of a trade agreement for 1957, recently concluded between representatives of importers and exporters of each country.

Brazilian Petrochemical Industry

The Brazilian National Petroleum Council has issued a resolution which makes it clear that private enterprise will be allowed free scope in the petrochemicals field. The national oil monopoly, Petrobas, will be entitled to intervene, however, if any one private company seems to be monopolising part of the industry or if private enterprise neglects any important petrochemical product.

Swiss-Austrian Link

Escher Wyss A.G., of Zürich, recently acquired large interests in Maschinenfabrik Andritz A.G., an Austrian firm with a similar production programme.

Portuguese Fertilisers and Pharmaceuticals

As part of a policy to enlarge the Portuguese fertiliser industry, the Estarreja factory is being extended to produce 90,000 tons annually and it is expected that the Uniao Fabril do Azoto factory will be enlarged to a similar capacity. It is also proposed to establish by 1959 a factory for the production of nitrogenous fertilisers from petroleum refinery by-products. The Government is studying how the Portuguese pharmaceutical industry can be enlarged within the framework of the second six-year development plan, 1959-64. It is hoped then to begin the manufacture of the most widely consumed products, including synthetic medicaments, vitamins and antibiotics.

French Natural Gas

Plans are in hand to build a factory to produce acetylene and ammonia from the gas deposits at Lacq. A group is also planning to make deuterium from sulphuretted hydrogen from the same gas deposits.

Pharmaceuticals in Persia

Following their efforts to control imports of pharmaceuticals, the Persian Government is examining various proposals for local manufacture and export of these products which have been submitted by foreign firms.

German Phthalic-acid Plant

A new phthalic-acid plant erected on the site of the Chemische Werke Carolinenglück, Bochum, and owned by Gelsenkirchener Bergwerks A.G. and the Badische Anilin- und Sodafabrik (BASF) was commissioned recently. It is designed to produce 1000 tons a year, but at present it is operating at about two-thirds capacity. Naphthalene produced as a by-product at the coking and coal-tar installation of Carolinenglück is used as the starting material.

Belgian Scientific Commission

The Belgian Government has set up a National Scientific Commission of eighteen members, of which King Leopold has agreed to become President. The terms of reference cover nuclear research and general problems which current scientific progress presents, together with their possible economic and social repercussions.

German Potash Production

West German potash (K_2O) production in 1956, 1,734,000 tons, was 10% more than in the previous year. The home market took 949,000 tons, in comparison with 898,000 in 1955. Exports rose from 680,000 tons in 1955 to 786,000 tons last year. Supplies to the traditional markets (United Kingdom, Denmark, Belgium, Holland, Sweden, Japan and the United States) were maintained and most of the increase in exports resulted from efforts which were made to open up new markets in Venezuela, the Philippines and other parts of the Far East.

Venezuelan Petrochemical Institute

The first phase of the construction of plant for the Venezuelan Petrochemical Institute has been completed to the extent of 60%. Initial production is at an annual rate of 10,000 metric tons of chlorine, 11,200 tons of caustic soda, and an increasing quantity of fertiliser, which it is hoped will eventually reach a rate of 150,000 tons yearly. The second phase, costing Bs. 250 million (£25.5 million), and starting late in 1957, is to consist of the production of explosives, herbicides, fungicides and natural gasoline. Also included in this phase is the development of the national gas pipeline network, for which the Institute is now responsible. The third phase, to cost Bs. 500 million (£51 million), and scheduled for 1958-60, is to include the production of synthetic rubber, plastics, lacquer and refined oils. By 1960 the total investment should have reached Bs. 1000 million (£102 million).

Fatty Acids in Belgium

The Archer-Daniels Midland Co., of Minneapolis (Va.), U.S.A., is to manufacture fatty acids and by-products in Belgium, in conjunction with Palmfina (a subsidiary of Petrofina). A new company, Oléochin, S.A., has been constituted for the purpose, and it is proposed to build a factory at Ertvelde (East Flanders) estimated to cost B.Frs. 100 million (£710,000). Production is scheduled to begin at the end of 1958, and when the plant is in full operation it will supply not only Belgium but other European countries and Middle East markets.

Caribbean Pasteurisation Plant

The equipment and machinery for a new milk-pasteurisation plant in Georgetown, British Eastern Caribbean, is being supplied by A.P.V., Crawley, Sussex.

Chemistry in North Staffs.

I.C.I. has given £10,000 to the North Staffordshire University College appeal fund, with the stipulation that the money shall be used in the college's department of chemistry.

Dutch Hydro-sulphide

The Royal Netherlands Salt Industry has under construction three buildings for the manufacture of hydro-sulphide. The process to be used is new, and production is expected to start by the middle of this year.

Ceylon Rubber Research

The Ceylon Institute of Scientific and Industrial Research is being presented with a British-made laboratory rubber mill for experimental research into the development of rubber and plastic materials.

New Brazilian Installations

Plant recently opened in Brazil include a fertiliser factory at Cubatao, Sao Paulo, which uses the by-products of the neighbouring oil refinery, and a new sulphuric acid plant having a capacity of 25 tons a day built for the Cia. de Industrias Electro-Quimicas, S.A.

New Plant for Chile

The Chilean Government has authorised the Braden Copper Co. to import new capital to the amount of U.S. $3.1 million for a new sulphuric acid plant having a capacity of 75 tons a day and for four condensing tanks of reinforced concrete. U.S. $1.4 million will be spent in Chilean currency and U.S. $1.7 million on imported equipment.

Developments in Holland

Dagra have announced plans to build in Holland a new factory for the manufacture of pharmaceuticals and other chemicals. At least 1,500,000 guilders will be invested in the development.

New Paint Solvents

Three new solvents, known as Aromasols H, C and L, for use in paints, lacquers and varnishes have been produced by the Billingham division of I.C.I. Aromasol L is described as a petroleum-derived toluene.

put it to the test!

These new pumps open up an extensive range of acids, alkalis and slurries to economical pumping. They are constructed in 18/8/3 Stainless Steel for mildly corrosive liquids or in WORTHITE, a super-resistance alloy steel enabling Sulphuric Acid to be pumped with negligible corrosion loss. Also, there is the added advantage of easy interchangeability of the Stuffing Box Packing with two types of Mechanical Seal to suit different processes — plus the embodiment of the well-known Worthington-Simpson "Monobloc" construction which means few parts, lower costs, less wear and easier installation.

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with all affected parts in
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STAINLESS STEEL
for mildly corrosive liquids or where contamination and discolouration of the liquid must be avoided

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ALSO AVAILABLE IN **'WORTHITE'**
a new alloy steel with exceptional resistance to many acids, alkalis and slurries

WORTHINGTON - SIMPSON
CHEMICAL PUMPS
A WIDE RANGE AVAILABLE

WORTHINGTON-SIMPSON LIMITED NEWARK NOTTS

PLANT EQUIPMENT NEWS

Capacity Level-controller

Elcontrol now have available a selection of proximity switches suitable for level control and indication of free-flowing solids and non-conductive or water-free liquids such as oils. Each switch basically consists of a control unit embodying a circuit operating a relay, together with a rod or plate electrode that is inserted into the vessel at the desired control level. The electrode, which is part of the electronic circuit, has a standing electrical capacity to earth, and this capacity is varied by the approach of a mass having a dielectric constant greater than that of air. When the capacity change is sufficient to bring the circuit into oscillation, the relay in the unit is operated and thus provides a signal or operation of a control mechanism—e.g., a gate, valve, conveyor motor, etc., as required. It is not normally necessary for the electrode to come into direct contact with the controlled substance. **Elcontrol Ltd., 10 Wyndham Place, London, W.1.**

BCE 1350 for further information

Boiler-level Control

A three-element drum water-level control system is now available as an integral part of any automatic boiler-control scheme produced by George Kent for water-tube boilers. The three elements are the measurement of feed-water flow, steam flow and drum water-level. Only standard instruments and components are employed in the system. **George Kent Ltd., Luton, Beds.**

BCE 1351 for further information

Synthetic Resin Plant

A special feature of the new universal synthetic resin laboratory plant manufactured by Wilhelm Schmidding of Cologne and available from Guest Industrials is the built-in hydraulic jack which enables the whole superstructure to be lifted clear of the pot for cleaning between batches. All parts coming in contact with the product are of stainless-steel Remanit 1880 SST (corresponding to V4AE). A cooling coil is welded to the vessel and this can be used for pre-heating with steam. The plant is made in the capacities 50, 70 and 120 litres and is equipped for direct gas or electric induction heating. **Guest Industrials Ltd., 81 Gracechurch Street, London, E.C.3.**

BCE 1352 for further information

Rotary Compressors

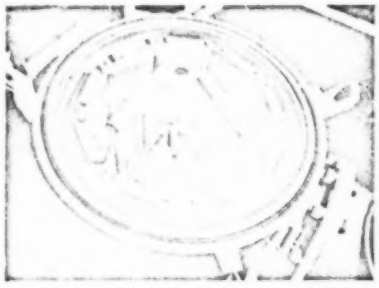
Whittaker, Hall are now producing a new range of Hydrovane rotary compressors of up to 600 cmf capacity. The illustration is of the 600-cfm Hydrovane (No. 18022) designed primarily as a stationary unit direct coupled to a flanged motor. All of the machines are air cooled and self-contained and, being flange connected to the motors, do not require any further alignment after mounting on simple foundations. The larger models comprise two stages of compression, each with its own pressure

lubrication and cooling system, which acts also as the sealing medium. There are no circulating pumps or valves. Oil separation is in three stages with full-flow filtering, and the discharged air is virtually oil-free. The machines contain few moving parts and wear is said to be negligible due to the copious supplies of oil. The oil circuits are self-draining and damage due to oil locks is not possible. Volume is controlled by a modulating suction valve. **Whittaker, Hall & Co. Ltd., Radcliffe, Manchester.**

BCE 1353 for further information

3000°C Furnaces

Graphite-resister furnaces capable of providing temperatures up to 3000°C have been developed by G.E.C. to meet the demand created by development work on, for example, atomic energy; on new metals such as titanium, tantalum and zirconium; for sintering; and for brazing components which will operate at elevated temperatures. The body of the furnace is a water-cooled, vertical, cylindrical steel tank with a hinged, domed lid. A vacuum-tight seal is formed between flanges on the lid and the furnace body. The charge is heated by radiation from a triangular-shaped assembly of graphite bars which surrounds the charge space. These graphite bars operate at a low voltage supplied by a three-phase transformer. A voltage regulator enables the secondary voltage of this transformer to be steplessly varied to give control over the heating rate. Radiation screens consisting of molybdenum sheets, arranged to enclose the heating chamber, provide the thermal insulation. The



vacuum pumping system consists of a gas ballast pump, a combined booster and oil-diffusion pump, and a valve block which controls the evacuation of the furnace chamber. The valve block is fitted with a five-position operating lever which can be moved only in one direction to ensure the right sequence of operations, and the operating vacuum is between 10^{-4} mm. and 10^{-5} mm. mercury. Safety devices give protection of both the furnace and the charge against possible failures in the electricity and water supplies. Maximum rating of the furnace is 120 kVA. The furnace will take a charge of about 9 in. in diameter and 12 in. high with a maximum weight of 90 lb. Provision is made for introducing a hydrogen atmosphere into the furnace chamber to hasten the later stages of cooling. **The General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.**

BCE 1354 for further information

pH Dose-rate Controller

The Lock *p*H dose-rate controller has been designed for use with Pye industrial *p*H measuring equipment for automatically regulating the flow of reagent to a process or effluent so as to maintain the *p*H within required limits. The output from the *p*H meter is fed into the dose-rate controller which carries adjustable high and low limit switches connected with output relays. The energising of either relay sets a two-stage timer into operation; the first time-stage energises a reversible electric motor in the motorised control valve to either increase or reduce the reagent flow. The motor operates for a preset time, at the end of which the second timer stage switches off the motor for another variable preset time. If at the end of this "wait" period the *p*H has been restored to its required value, no

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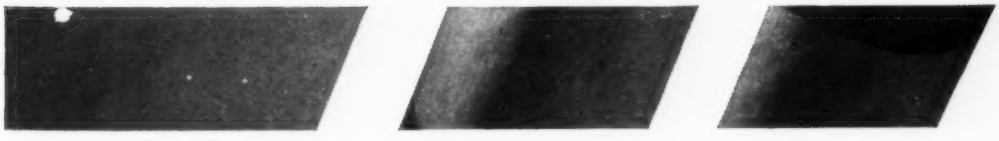


PLANT EQUIPMENT NEWS

further action takes place until another deviation outside the set limits occurs. If, however, the *p*H is still outside its limit the cycle of events repeats. The use of the wait period prevents hunting of the control system. **A. M. Lock & Co. Ltd., 79 Union Street, Oldham, Lancs.**

BCE 1355 for further information

Vacuum Impregnation Plant

A self-contained, semi-automatic impregnation plant has been made available by General Engineering. All services on the equipment are controlled by electro-magnetically-operated valves, and a single multi-position switch provides effective interlocking and prevents mistakes by unskilled operators. **General Engineering Co. (Radcliffe) Ltd., Station Works, Bury Road, Radcliffe, Lancs.**

BCE 1356 for further information

Plastic Plant

Prodorite are now able to offer a complete range of pipes, "T"s, "Y"s, elbows, bends, branches, etc., in six plastic materials. The products include rigid P.V.C., nitrile rubber/P.V.C., polythene of high- and low-pressure types, nylon, styrene, acrylonitrile and resin/glass laminates. The range in pipe-diameter sizes of up to 6 in. is available in most cases from stock in all the materials mentioned. Most of the equipment is manufactured to B.S.S. 1600, 1387 and A.P.I.5-L. For chemical and construction engineering purposes, flat sheet and jointing strips are also included in the range, and pipes capable of continued use under conditions of high pressure or high temperature come within the scope of the service now offered. **Prodorite Ltd., Eagle Works, Wednesbury.**

BCE 1357 for further information

Packings and Seals

A new technique for manufacturing "U" and "V" ring packings in polytetrafluoroethylene (PTFE) has been elaborated by Crane Packing. It produces a fine finish to the surfaces and clean, accurately-formed lips, which, it is said, is impracticable with conventional moulding techniques. The company can now supply their Standard mechanical shaft seals with Coromant hard-metal opposing faces of the insert type. They are designed to handle abrasive products, such as calcium sulphate slurry, suspension of powdered pumice, rouge, suspenwater, etc., but are also suitable for mildly corrosive liquids, organic solvents, and alkalis such as sodium carbonate. They are not suitable for concentrated acids. **Crane Packing Ltd., Slough, Bucks.**

BCE 1358 for further information

Antibiotic Mill

The latest addition to the range of Apex comminuting mills is type B, produced for the sterile processing of antibiotics and other pharmaceuticals and chemicals, including suspensions. Particle sizes from 3 to 10 microns are obtainable with it and the output is more than 100 lb. an hour. The machine has reduced procaine penicillin to an average particle size of about 10 microns at a rate of 150 lb. per hour. It is equipped with swinging impact-blades which have a flat face for pulverising and a cutting edge for granulation, mixing and blending of wet or dry materials. All parts of the mill that come into contact with the materials being processed are of stainless steel, and the machine may readily be taken apart for cleaning and sterilisation. The grinding chamber and feed throat are water-jacketed to enable the operating temperatures of heat-sensitive materials to be controlled. A variable-speed, motor-driven screw feeder is fitted. **Apex Construction Ltd., 15 Soho Square, London, W.1.**

BCE 1359 for further information

Submersible Pump

A new electric submersible drainage pump has been designed by Sumo which can operate completely or partly submerged on full bore or "on snore" and can be left running, it is said, indefinitely. The pump can be suspended by its rising main pipe or by ropes. Fitted with a single-stage bronze impeller mounted below the motor on the stainless-steel rotor shaft extension, it will deal with any water-containing solids which can pass through the $\frac{1}{4}$ in. square mesh of the stainless-steel strainer. The impeller and the wearing ring surrounding its inlet, which are easily removable, are the only major components of the pump subject to wear when pumping abrasive particles. The main body and end caps are made of aluminium alloy. Provision is made in the pump inlet for a hose connection from an external water supply to form a jet into the pump impeller which can be used for cleaning purposes or for agitating excessive mud or sludge drawn in the pump. The interior of the squirrel cage motor is filled with a light oil which lubricates the lower journal bearing; the upper bearing, which also takes the thrust load, is situated in a grease-filled compartment. The unit is supplied fully lubricated, ready for service and requires no priming on arrival. On leaving the impeller the water flows through a coaxial passage-way surrounding a large area of the motor-housing outer walls to cool the stator. **Sumo Pumps, Ltd., Crawley, Sussex.**

BCE 1360 for further information

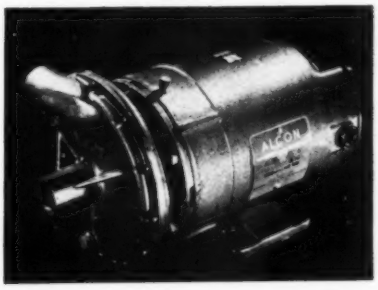
Electronic Digital Computer

A general-purpose digital computer of special use in solving mathematical, engineering and scientific problems has been developed by Metropolitan-Vickers. It is known as the Metrovick 950 and consists of five main parts—input equipment, store, arithmetical circuits, output equipment, and control panel. Information is fed into the machine by means of a photo-electric punched paper-tape reader, the paper tape having a five-hole code. The machine works in the binary notation and, the makers say, is of simple and compact design. **Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester, 17.**

BCE 1361 for further information

Non-self-priming Pump

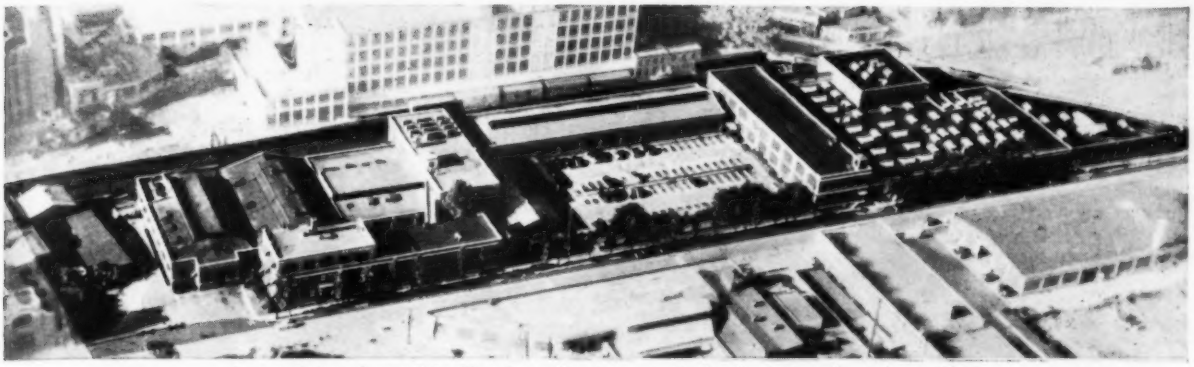
The new Alcon $\frac{3}{4}$-in./1-in. non-self-priming electric pump is of straightforward centrifugal construction and is made from gravity die-castings of aluminium. It has been designed for compactness and rigidity, and its outstanding feature, the makers say, is that it is an integral part of the electric motor, and this enables the pump to withstand external blows. It is powered by a 0.33-h.p. Brooks motor, having a speed of 2850 rpm, and it embodies a mechanical face-type seal having a carbon running face. **Arthur Lyon & Co., (Engineers) Ltd., 6 Carlos Place, Grosvenor Square, London, W.1.**



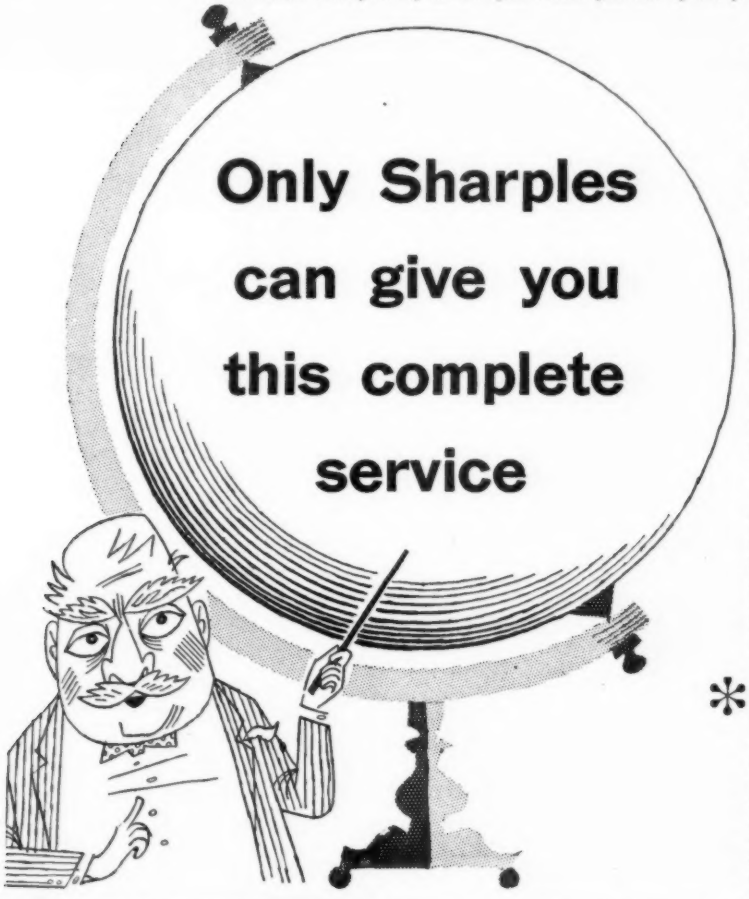
BCE 1362 for further information

Liquid-level Controller

Fisher have just commenced manufacture of type 779K pilot. Although this has been designed primarily for use with liquid-level controllers of the ball float type, it is usable with any measuring device capable of producing a force necessary to displace a small pusher rod or plunger. The pilot and ball float operate a diaphragm motor valve. The pilot operates on compressed air, non-corrosive gas or clean water at 20 to 70



An aerial view of one of the Sharples works—just one of the plants throughout the world.



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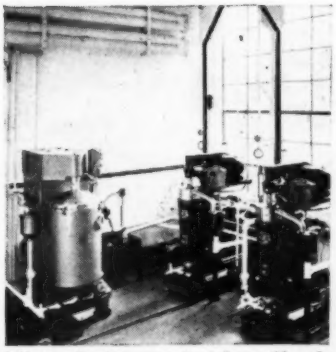
The light machine shop in the Lightpill plant. An entirely new Sharples factory has nearly been completed at Camberley, Surrey.



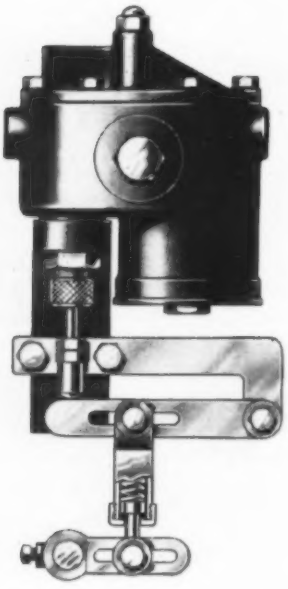
Full-size development plant for a Sharples process. This is regularly in operation adding to Sharples' extensive knowledge of separation problems.

SHARPLES

Sharples Centrifuges Ltd., Tower Works, Doman Road, Camberley. *Camberley* 2601

PLANT EQUIPMENT NEWS

psi, always delivers a given pressure to the diaphragm for a given level position, and requires no auxiliary regulator as the pilot also acts as a reducing valve. The makers say that the pilot is simply but



ruggedly constructed, and is unaffected by vibration. **Fisher Governor Co. Ltd., Airport Works, Maidstone Road, Rochester, Kent.**

BCE 1363 for further information

Gamma Gauge

Ekco have produced a gamma gauge for measuring fluid density. It consists of cæsium^{137} gamma-ray source mounted on one side of the pipe containing the liquid, and a pressurised ionisation chamber on the other. Output from the measuring head is measured by an indicator unit. Using a pipe of 8 in. diameter through which petroleum is passing, changes of density of 0.0002 gm. per c.c. can be detected. **Ekco Electronics Ltd., Ekco Works, Southend-on-Sea.**

BCE 1364 for further information

A Plastic Pump

A plastic pump made by Vanton, of New Jersey, U.S.A., for use in laboratory, pilot-plant and production-line handling of corrosive chemicals and fluids which must be maintained free of contamination is available from Howe & Co., and will be produced by them in Britain under licence soon. The pump possesses no stuffing boxes, shaft seals, gaskets, glands, or internal check valves. The only parts in contact with the fluids are the outer surface of the precision-moulded flexible liner and the inner surface of the body block. The proper selection of the material for these parts makes the pump adaptable for use with a wide range of fluids. It is self-priming and self-lubricating and handles volumes of up to 20 gpm. Pumping is by a rotor, mounted on an eccentric shaft, creating a progressive squeegee action on the fluid. **V. A. Howe & Co. Ltd., 46 Pembridge Road, London, W.11.**

BCE 1365 for further information

Diaphragm Compressor

Hymatic Engineering have developed a new twin-cylinder diaphragm compressor, type DP.14, which is capable of continuous operation at pressures up to 50 psi. It is specially suitable for the supply of clean air in, for example, the pharmaceutical, food and brewing industries. The diaphragms are of multiply high-temperature neoprene, laminated with nylon, and, as both delivery and suction valves are positioned on the same side of the compression diaphragm, the equipment is suitable for closed-circuit applications. The valves are of the reed type and are constructed of stainless steel. **Hymatic Engineering Co. Ltd., Redditch, Worcs.**

BCE 1366 for further information

Fire-damp Interferometer

Degenhardt have been granted duty-free Treasury licences for the importation of Carl Zeiss fire-damp interferometers. These instruments are designed for the rapid detection and easy measurement of gases—particularly fire-damp—in the atmosphere. Their small dimensions and weight enable them to be carried in the pocket. Measurement is carried out by the use of interference stripes. Particular care has been taken to make the instrument fire-damp proof, so that it can be safely used in coal mines and other undertakings in which there is risk of explosion. Double electric wiring is used and the instrument is thoroughly insulated and provided with a magnetic locking device. The lamp, batteries, absorption tube and the chambers themselves are accessible only with the aid of a powerful magnet. **Degenhardt & Co. Ltd., 32 Maddox Street, London, W.1.**

BCE 1367 for further information

Oxidation of Fumes

Holmes have introduced into Great Britain equipment for an oxidation process for the conversion of objectionable fumes to odour-free gases. It is to be known as the Holmes-Catco process. The catalytic combustion, it is claimed, has no minimum fuel air limits, and the oxidation temperature is no more than about 500°F. The temperature rise of the fumes passing through the catalyst element is proportional to the concentration of combustible material which they contain. The heat liberated per unit quantity of hydrocarbons is the same as with flame combustion. With catalytic combustion there is no flame, but the catalyst may glow at high fume concentration. The catalyst element is a frame on which a narrow heat- and corrosion-resistant nickel alloy ribbon enclosed between heat-resistant alloy container screens is mounted; a coating of metals of the platinum group is bonded to all surfaces of the nickel alloy ribbon to form the catalyst. The element is of sturdy construction, and in appearance resembles a metallic air filter mat. Elements of standard dimensions can be grouped to handle any desired volume of fumes. The pressure drop across an assembly is low. Reactivation of a catalyst element is carried out at a small cost. **W. C. Holmes & Co. Ltd., P.O. Box No. B7, Turnbridge, Huddersfield.**

BCE 1368 for further information

Hard Polythene Valve

A ball-valve made completely of hard —high density—polythene is being manufactured by Fordhams, who claim that the fitting will not be prone to sticking

and will not corrode. The valve rubber, a disc 1 in. in diameter, can be replaced without dismantling the ball-arm or using any tools. **Fordham Pressings Ltd., Melbourne Works, Dudley Road, Wolverhampton.**

BCE 1369 for further information

Electrical Weighing System

Elliott Brothers are making available an electrical weighing system which depends on the use of load cells that measure the weight of the container complete with its contents. The tare weight of the container is permanently offset, so that a direct indication of the net contents is shown. The load cells are hermetically sealed and the apparatus contains no knife-edges or levers. It is suitable for measuring and controlling the contents of hoppers, bins and tanks

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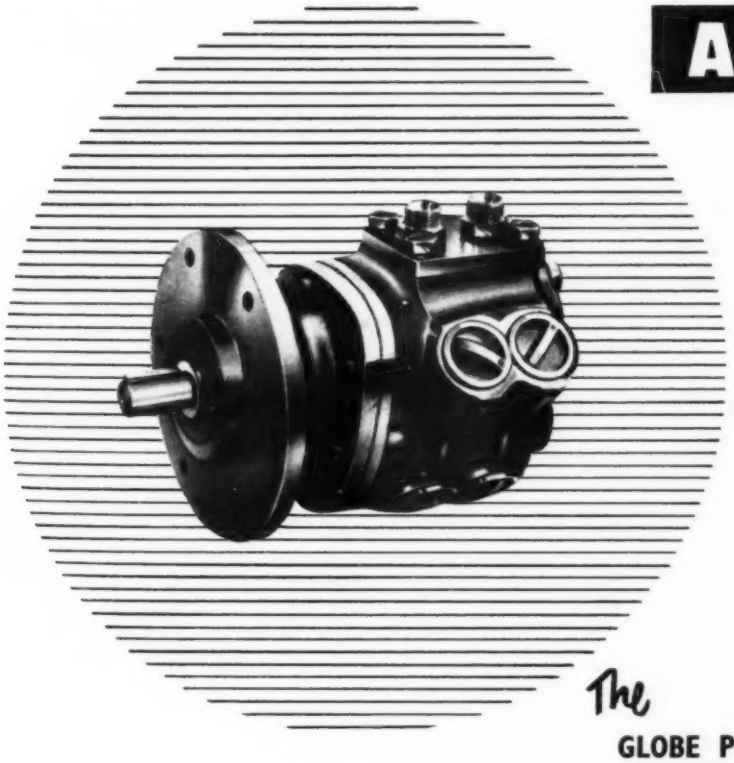

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BCE 1315 for further information

PLANT EQUIPMENT NEWS

for stock-control purposes, to maintain fixed contents levels, or to charge or discharge predetermined quantities and for automatic control of proportioning and blending processes. **Industrial Weighing Division, Elliott Brothers (London) Ltd., Century Works, London, S.E.13.**

BCE 1370 for further information

New Laminating Resin

Bakelite are now making a new low-pressure phenolic resin from which laminates having good mechanical properties can be made. Glass laminates produced from the resin can be used at temperatures of up to 200-250°C without serious loss of strength it is claimed. In addition, the resin has good wetting powers for fibrous materials such as glass, asbestos and cellulose; in the form of a laminate, it can be cured at moulding pressures as low as 10 lb./sq. in.; and glass-cloth laminates made from it have good heat resistance. **Bakelite Ltd., 12 Grosvenor Gardens, London, S.W.1.**

BCE 1371 for further information

Radiation Thickness Gauge

Radiation thickness gauge, type 170, developed recently by I.D.L. in collaboration with Davy & United Engineering, has been designed to provide accurate thickness indication in the metals industry with a fast response time (0.05 sec.), and to make no contact with the material under inspection. The standard thickness range is 0.005 in. to 0.025 in. of steel, and the source of radiation is an artificially produced radio-isotope, housed in the lower arm of the yoke assembly. For most applications the source unit requires no attention for at least 15 years. Replacement is inexpensive and simple. **Isotope Developments Ltd., Beenham Grange, Aldermaston Wharf, Reading.**

BCE 1372 for further information

Welding Electrodes

Three new welding electrodes which are suitable for either a.c. or d.c. supply have been added to the range manufactured by Quasi-Arc. They are Ferroloid No. 3, a development in the 55/45 nickel-iron class; Chromoid No. 4 electrodes, which deposit weld metal of 18/8/3 chromium-nickel-molybdenum composition stabilised with niobium; and Chromoid No. 5 electrodes which deposit fully-austenitic stainless steel of 25/20 chromium-nickel composition, the weld metal containing less than ½% ferrite. Chromoid nos. 4 and 5 are said to be particularly suitable for use in the chemical engineering and oil-refining industries. **Quasi-Arc Ltd., Bilston, Staffs.**

BCE 1373 for further information

Step Pulse Technique

Apparatus for step-function pulse technique in ultrasonics, enabling direct echoes to be obtained from distances as small as 0.020 in., is being made by Ultrasonoscope. The technique may be applied to flaw detection, thickness measurement and allied problems. In its use a square wave is used, the duration of which is sufficiently long for echoes generated by the leading edge to arrive back before the trailing edge of the wave affects the receiver. A direct-reading scale is provided. **Ultrasonoscope (London) Ltd., 47c Sudbourne Road, London, S.W.2.**

BCE 1374 for further information

Gas-liquid Chromatography

Pye are developing a range of equipment for qualitative and quantitative analysis, using the new gas-liquid chromatography techniques. At present they can supply the following component parts: Katharometer, No. 11900, a thermal conductivity cell manufactured in copper; Katharometer control unit, No. 11910, which combines the functions of detector bridge and current control for the platinum detector wires; and d.c. microvoltmeter/amplifier, No. 11340/S. **W. G. Pye & Co. Ltd., Granta Works, Newmarket Road, Cambridge.**

BCE 1375 for further information

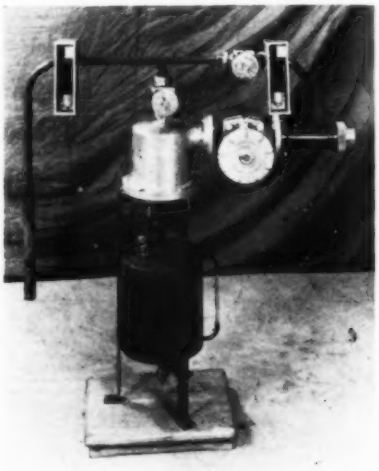
Water-hardness Monitor

A new water-hardness monitor has been developed by Nash & Thompson in conjunction with the Central Electricity Authority for use in industrial boiler-houses. It will sound an alarm or initiate corrective action when the total hardness content of the feed water being monitored exceeds a preset figure. This can be as low as two or three parts per million of calcium carbonate. For estimating hardness, the method of titration with the disodium salt of ethylenediamine tetra-acetic acid is used. A solution of this salt, ammonia buffered, an indicator solution of erichrome black and the water under test are all fed at controlled rates into a mixing vessel. The colour of the resulting mixture changes sharply from blue to red as the hardness of the water rises past a value dependent on the concentrations and flow rates of the solution. The mixed solutions are examined in an optical cell through which passes a beam of red light, the amount of light transmitted rising sharply as the mixture changes colour. This light falls on a photocell which operates a relay as the colour changes, and this relay, in turn, controls the alarm circuit and any external circuits which are necessary to change over or regenerate the water-softening plant. **Nash & Thompson Ltd., Oakcroft Road, Chessington, Surrey.**

BCE 1376 for further information

Vacuum Equipment

Vacuum equipment recently developed by Edwards includes the Speedivac U-tube gauge for condensable vapours. It is based on a mercury U-tube manometer and incorporates an integral electrical heating element to maintain a temperature of 50°C. The instrument can be used for water-vapour containing vacuum systems in the range 0.5 to 90 mm. of mercury without condensation difficulties.



In the new model VS6 vacuum-switch, controller switching is carried out, through a thyraton relay, by the movement of an evacuated and sealed capsule. The contact position of this is adjustable, according to the pressure required, in the range 0.5 to 20 or 1.0 to 40 mm. of mercury.

The company has developed new unlubricated Speedivac pumps for uses where oil contamination must be avoided, and for the suppression of oil mist from mechanical vacuum pumps—a trouble particularly difficult when pumps are air ballasted. They are now utilising porous ceramic filters of suitable grade. **Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.**

BCE 1377 for further information

Fault Alarm

An automatic system for giving warning of faults on unattended premises, which makes use of existing public telephone-lines, has been developed by Auto Call. It consists of a Post-Office-approved automatic telephone dialling machine which, on receipt of a signal

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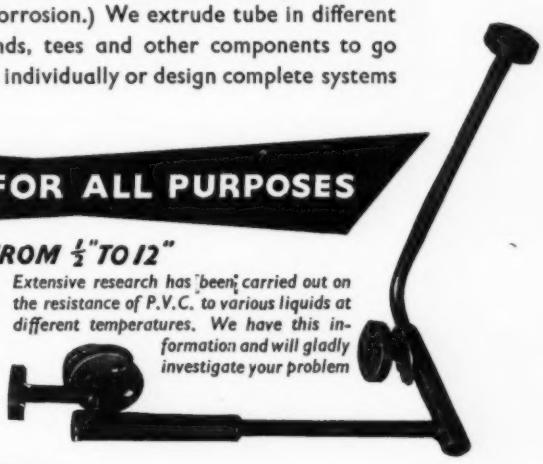

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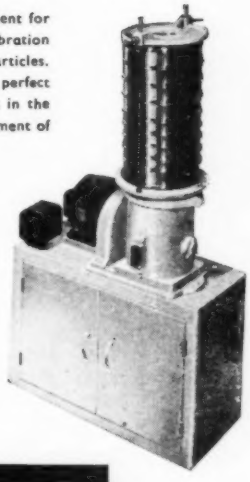

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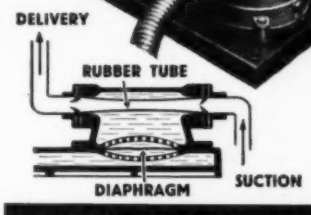

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BCE 1318 for further information

PLANT EQUIPMENT NEWS

indicating a fault, sends out a recorded message over the G.P.O. lines to a control room. The message is repeated for, if necessary, periods of four minutes, to give ample time for it to get through. On receipt of the message, the control-room operator has only to telephone back to the number given on the recording, and the machine will acknowledge his call, cancel all further messages and automatically reset. **The Auto Call Co. Ltd., 40 Parker Street, London, W.C.2.**

BCE 1378 for further information

Level Indicators

Edward Hall have developed a continuous level indicator which comprises a vertically mounted electrode unit that

may be fixed in a container holding any type of conducting or non-conducting liquid or solid material by use of a selector switch and group indicator cabinet. The levels in up to 36 containers can be checked at any instant. **J. Edward Hall (Elec. Engineers) Ltd., Clarence Road Works, Leeds, 10, Yorks.**

BCE 1379 for further information

A redesigned liquid level indicator, the Teledep mark II, is being produced by Dobbie McInnes. Maintenance consists merely of giving the piston valves a quarter turn by hand, pulling them clear and wiping them clean. It also has the advantage of registering the required depth of liquid in a ship's tank when the ship has a list. In producing the mark II, the instrument was modernised in appearance; the valves are now stowed behind the indicator space. **Dobbie McInnes Ltd., Broomloan Road, Glasgow, S.W.1.**

BCE 1380 for further information

Adhesive Tapes

Vylap pipe protection tape recently made available by Gosheron is a P.V.C. tape in which the self-adhesive properties are inherent in the tape itself. Vylap, it is claimed, is tough, has a high electrical insulation and excellent resistance to acids, alkalis, fungi, bacteria and the elements. Dilec No. 7 electrical P.V.C. tape, which is being produced by the same company, also has inherent self-adhesive qualities. **John Gosheron & Co. Ltd., 79 Albert Embankment, London, S.E.11.**

BCE 1381 for further information

New Publications

Leaflet BT. 156, entitled "Equipment for the Petroleum Industry", has recently been issued by Metal Propellers Ltd., and describes the wide range of distillation equipment and stainless-steel process plant manufactured by the company for the chemical industries. Metal Propellers Ltd., 74 Purley Way, Croydon, Surrey.

BCE 1382 for further information

Talbot Stead have produced a handy-sized "Blue Book" of useful engineering data. The booklet presents in a compact form data on tubes and bars, flanges, fittings and manipulated products. Talbot Stead Tube Co. Ltd., Green Lane, Walsall.

BCE 1383 for further information

B.T.P. No. 46 (Home Edition) details the many advantages of Anatase LF, a new fine particle, modified titanium oxide pigment. British Titan Products Co. Ltd., Coppergate, York, England.

BCE 1384 for further information

"Linde Molecular Sieves" is the title of a recent booklet by B.D.H. It describes a new series of drying agents which possess novel properties of selective adsorption. The British Drug Houses Ltd., B.D.H. Laboratory Chemicals Group, Poole, Dorset.

BCE 1385 for further information

Fry's Diecastings Ltd., Midland Works, Brierley Hill Road, Wordsley, near Stourbridge, have informed us that copies of their technical publications on gravity and pressure die-castings are available free of charge.

BCE 1386 for further information

A new catalogue (CH400) by Hilger & Watts Ltd. describes this company's recently-introduced Fluorite Polychromator, an instrument for the analysis of carbon, phosphorus and sulphur in steel. Hilger & Watts Ltd., 98 St. Pancras Way Camden Road, London, N.W.1.

BCE 1387 for further information

"Monsanto Chemicals and Plastics" is the title of an attractive and well-presented publication by Monsanto which describes the company's products in these fields and the industries served. Monsanto Chemicals Ltd., Monsanto House, 10-18 Victoria Street, London, SW1.

BCE 1388 for further information

A new publication, "Wakefield Lubrication Equipment Speeds Production", deals with oil and grease lubricators, mobile lubrication equipment, the lubrication of pneumatic equipment and automotive equipment. Copies from P.D. Department, Wakefield-Dick Industrial Oils Ltd., Grosvenor Street, London, W.1.

BCE 1389 for further information

"Steels and other Metals" used in the manufacture of Accles & Pollock tubes is a useful publication by this company, which describes the range of steels and other metals used for tubes by Accles & Pollock Ltd., Oldbury, Birmingham.

BCE 1390 for further information

Bedlam's Lascar Manual of Jointings and Packings has been compiled, the company state, with the intention of assisting all users of the company's products to derive the fullest benefit from their correct application in service. The manual itself is admirably presented and printed. Bedlam Asbestos Co. Ltd., Lascar House, Hounslow, Middlesex.

BCE 1391 for further information

"Automation for Vials" is a new leaflet describing in several languages Autopack's vial feeding, filling, rubber bunging, and cap spinning machine. Autopack Ltd., Birmingham, 3.

BCE 1392 for further information

Johnson, Matthey have recently published a tastefully produced booklet which, as the company's chairman says in his foreword, "has been issued in the hope of giving an idea of the company's work today". Johnson, Matthey & Co. Ltd., Hatton Garden, London, E.C.1.

BCE 1393 for further information

E.177 is a revised catalogue by Edwards High Vacuum Ltd., and describes the ½-lb. Vacuum furnace manufactured by the company. The company state that this small, versatile furnace will prove of great value to metal workers for the brazing of titanium. Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.

BCE 1394 for further information

A new 24-page catalogue describing their range of air-powered grinders has recently been issued by Consolidated Pneumatic Tool Co. Ltd., 232 Dawes Road, London, S.W.6.

BCE 1395 for further information

"Super Duty Refractory Concretes" is the title of a brochure on Secar 250, a high-purity white calcium-aluminate cement capable of withstanding temperatures up to 1800°C (3300°F), which is now being marketed by Lafarge Aluminous Cement Co. Ltd., 73 Brook Street, London, W.1.

BCE 1396 for further information

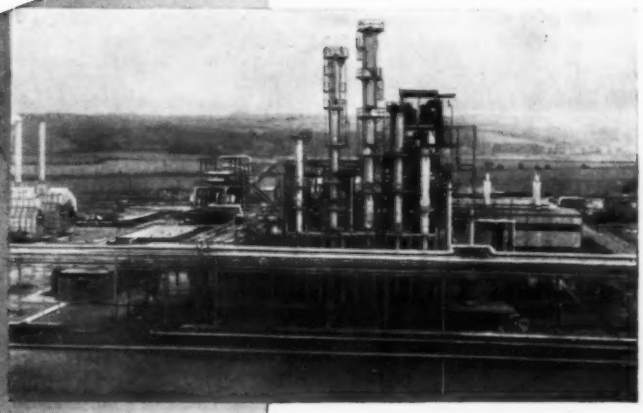
"Ten Amazing Years" is the title of the booklet published by Fieldens to commemorate the company's tenth anniversary. The publication covers the range of products manufactured by the company and contains some interesting articles on specific applications. Fielden Electronics Ltd, Wythenshawe, Manchester.

BCE 1397 for further information

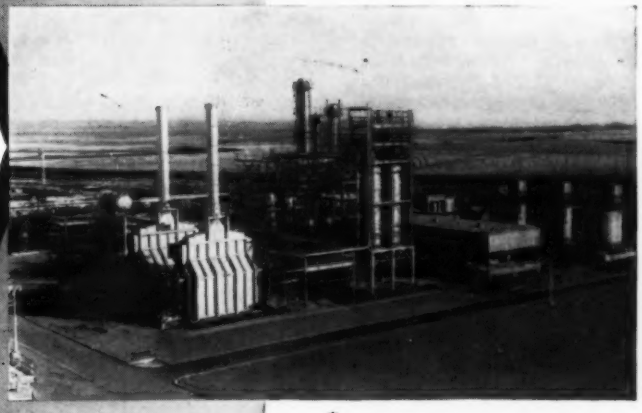
BCE 1306 for further information

RECENT WORK in Petrochemicals

These are examples of Badger-built Petrochemicals plants commissioned within the past six months. Their design is the product of many years of experience and takes advantage of the latest American developments available to us through our U.S. affiliate.



ETHYLENE FROM NAPHTHA—U.K.
(By Courtesy of British Hydrocarbon Chemicals Ltd.)



* SYNTHETIC ETHANOL—U.K.
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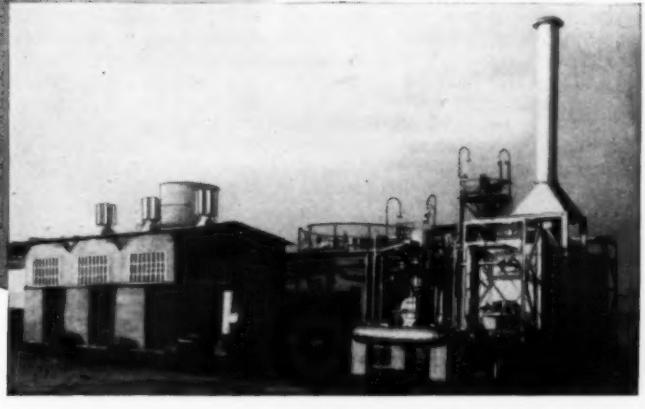

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Month's News in Brief

A new joint company—Davy British Oxygen Ltd.—has been formed which make available to the steel industry "oxy-steel" processes utilising the steel plant manufacturing resources of Davy and United Engineering Co. Ltd., Sheffield, and the metallurgical techniques and tonnage oxygen plant manufacturing facilities of British Oxygen Engineering Ltd., and British Oxygen Linde Ltd. The capital of the new company will be held equally by Davy and United Engineering Co. Ltd. and by The British Oxygen Co. Ltd., and the directors will be: Mr. M. A. Fiennes and Mr. M. F. Dowding of Davy and United Engineering Co. Ltd., and Dr. P. H. Sykes and Mr. F. J. Clark, of The British Oxygen Co. Ltd. The registered offices will be Bridgewater House, Cleveland Row, St. James's, London, S.W.1.

The Registrar of Restrictive Trading Agreements has announced that the public register of agreements is now open for inspection from 10 a.m. to 4.30 p.m. daily, except on Saturdays, Sundays and certain holidays. The register may be inspected on payment of a fee of 1s. a day in London on the seventh floor at Chancery House, Chancery Lane, W.C.2; in Edinburgh at 9 Wemyss Place, Edinburgh, 3; and in Belfast at Chichester House, 64 Chichester Street. There will be a public search room at each of these addresses, together with indexes of the commodities which are the subject of agreements on the register.

Baldwin Instrument Co. Ltd. has joined the group of companies controlled by C. E. Harper Aircraft Co. Ltd. The present range of the company's products will continue, with increasing emphasis on industrial application of nucleonics, electronics and fluid power equipment. Over the next four years, manufacturing facilities will be considerably expanded, as will research and development. Baldwins will continue to operate as a separate company but will be supported by the larger resources of the Harper group, which consists of Harpers, the parent company; The Stanley Engineering Co. Ltd.; H.M.C. Wheels Ltd.; and Electrical Screw Ltd.

During 1956 The Royal Dutch/Shell Group of companies ordered in the U.K. materials and equipment to the value of £58 million, breaking the previous year's record by £8 million. £44 million worth, or more than 75% of the total, is for export and £14 million worth is for delivery in the U.K. to maintain and expand refineries and research establishments in this country. Additionally, many millions of pounds were spent on the construction, repair and victualling of the Shell tanker fleet.

Durham Raw Materials Ltd. have opened a new technical service laboratory at Camberley. The new laboratory will supplement the work done by the company's large technical centre at Birtley, Co. Durham, and its facilities will be freely available to firms wishing to assess the advantages of the du Pont group of products. Mr. Marshall Pike, who is an associate of the Institute of the Rubber Industry, is in charge of the new laboratory.

The American Atomic Energy Commission has awarded the Babcock & Wilcox Company of New York a $9,872,000 contract for the design, development and fabrication of a nuclear reactor and components of the propulsion plant for a nuclear-powered merchant ship. The ship is being built as a joint project of the Commission and the Maritime Administration of the Department of Commerce.

The Balfour Group of Companies is planning the establishment of extensive new laboratories for the research and development of chemical and chemical engineering plant. The parent company, Henry Balfour & Co. Ltd., has decided to purchase a large site of approximately 25 acres, close to their existing works at Leven, Fife, for this purpose.

Tube Investments have announced the formation of a new subsidiary company, Old Park Engineering Ltd., of Dudley, Worcestershire, to take over general welded fabrications and structural work previously carried out at Round Oak Steel Works Ltd. A new 80,000 sq. ft factory is being equipped for the new company.

An agreement involving broad cross-licensing of patents as well as a full interchange of technical and manufacturing information has been entered into by Graviner Manufacturing Co. Ltd. and Fenwal Incorporated. Under this agreement, the two firms license each other to manufacture and sell their proprietary products within their respective marketing areas.

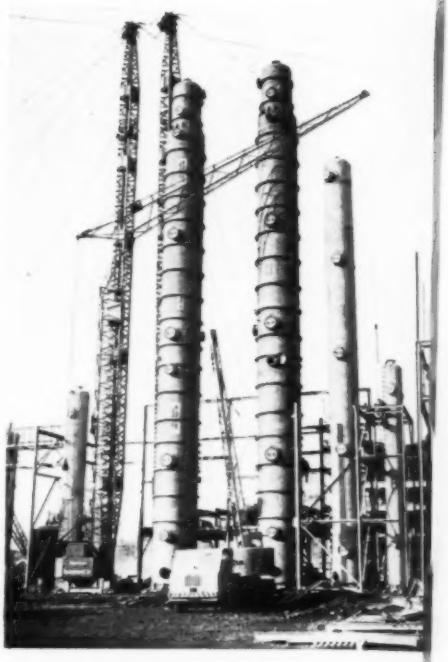
Ether Ltd. expect by the end of 1957 to have a comprehensive range of entirely new types of Ether process control equipment available, and, to meet the expansion of business which will ensue, a further factory of 60,000 sq. ft is now under construction.

The Rt. Hon. Lord Tedder, Chancellor of the University of Cambridge, will open the new metallurgical laboratories of the British Welding Research Association at Abington Hall, Abington, near Cambridge, on July 23.

Torrance & Sons Ltd., Bilton, near Bristol, have informed us that they are the manufacturers of the continuous batch mixing plant, details of which were given on p. 280 of our May issue, and not Holmes Bros., a subsidiary company.

Albright & Wilson Ltd.'s head sales office moved to 1 Knightsbridge Green, London, S.W.1. Telephone KENsington 3422, on May 6.

Londex Ltd. have informed us that the telephone number of their Anerley works is now SYDenham 3111 and the main works number SYDenham 6258.



I.C.I.'s Billingham oil gasification plant, now being built, is reported as unique in Britain. Nowhere previously in this country has this series of processes been grouped together to produce gases for ammonia manufacture. This complete break from the long-established method of gas production for ammonia has meant the spending of several million pounds on the plant, but it does not displace the present method. Up to the stage where the gases are brought together in the synthesis plant the two methods will be operated side by side. One of the great virtues of the new process is that the gases are produced under pressure. Application of this principle cuts out some of the extensive compression operations in the ammonia process as now carried out. When completed, it will be the most highly instrumented plant in the factory. It forms part of an expansion programme at Billingham, which needs a much greater output of ammonia. Our illustration shows the towers which will form part of the new gasification plant.

Francis Morton & Co. Ltd., constructional engineers of Liverpool, announce the acquisition of the issued capital of Bates & Bates Ltd., of Birmingham, specialists in welding and welding controls. Mr. C. R. Bates continues as managing director.

The former Institute of Seaweed Research buildings at Inveresk, Musselburgh, were officially opened by Lord Strathclyde as the Arthur D. Little Research Institute on March 22. The directors are Raymond Stevens, Dr. D. W. Bass and W. A. W. Krebs, president and vice-presidents respectively of Arthur D. Little Inc., Sir Ian Heil-

Here's the true story of a producer of a high value organic salt who had the job of separating fine crystals from the hot mother liquor

BEFORE A new plant, nearly a million pound investment, was struggling to produce a quarter of its rated output. The reason was a bottle-neck in removing fine crystals of a by-product from a saturated liquor at about 110°C. A screen-type continuous centrifuge installed for this duty proved extremely fussy as regards feed slurry consistency : a little too thin and crystals were lost to the filtrate and liquor flooded over to the cake discharge. Prethickening the slurry to avoid the trouble caused endless difficulties in pipe runs to the centrifuge, since any hold-up or cooling meant a solid block up from end to end. And hold-ups were frequent since the liquor cooled down in the centrifuge and the perforations soon blocked with product salting out from the mother liquor.

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AFTER an 18″ × 28″ Bird Solid Bowl Continuous Centrifuge was installed as a stop-gap. From the first day this small machine handled the entire throughput continuously without shut-downs. No prethickening was required. The temperature drop in the machine was only a few degrees, the filtrates ran gin clear and the crystals, washed free of mother liquor, were dry enough to bag directly. More product came off in the first week than in any previous month. What a gap —but what a stop !

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bron. Dr. S. Anderson and Sir Robert Erskine-Hill, Bt., with Lord Bilsand as chairman. Dr. F. Neville Woodward continues as director of the new Institute.

By means of a newly completed extension, it is planned to increase the output in the heavy constructional shop of Newton, Chambers & Co. Ltd., Thorncliffe, near Sheffield, by a further 50%.

The proposed nuclear power station to be built at Hinkley Point, Somerset, will be by far the largest in the world. The Central Electricity Authority is expected to place an order for one station of the new plant within three months of final approval being given for site development. Reported to be in negotiation with the C.E.A. with an advanced design project for the site are the English Electric-Babcock & Wilcox-Taylor Woodrow consortium.

Shell Chemical Co. Ltd. and O. & M. Kleeman Ltd. announce that arrangements have been made whereby O. & M. Kleeman or its subsidiaries will have certain plastics raw materials manufactured by Shell Chemical or its associates, which will be marketed under the trade names of O. & M. Kleeman. Under this arrangement, Kleestron Ltd. a subsidiary of O. & M. Kleeman will have its polystyrene manufactured at the Partington plant of Styrene Products Ltd., an associate of Shell Chemical. Kleestron will continue to operate as an independent organisation marketing their products in the same manner as they have done since they began production of polystyrene in 1951, and their selling arrangements and policies, both at home and abroad, will be maintained.

Courtburn Positioners Ltd., manufacturers of positioning and work-handling equipment for welding, have formed a new associated company to handle the marketing of equipment for the welding industry, other than that manufactured by the parent company. It is registered as Courtburn Supplies Ltd. All the directors of Courtburn Positioners Ltd. are on the board of the new company.

Mitchell Engineering Ltd., of London, working as a consortium with their American associates, A.M.F. Atomics Inc., and Siemens-Schuckertwerke of Erlanger are to supply an atomic power station to the largest power organisation in the Ruhr, Rheinisch-Westfalisches Elektrizitatswerk A.G. This reactor for the Federal Republic will provide the first practical contribution to the introduction of nuclear power in Germany and is stated to be the first large-scale reactor contract to be obtained for export by a British company.

The Society of Chemical Industry has announced that applications for the John Gray Jubilee Scholarship must be made before September 1, 1957. These should be sent to the General Secretary, Society of Chemical Industry, 14 Belgrave Square, London, S.W.1. The scholarship is for £150 and is tenable for one year at any approved university or technical college. Candidates, who may be of either sex, should be graduates in chemistry whose intention it is to enter industry, but those awaiting the result of their final degree examination may apply.

Klockner Moeller England Ltd., a new company, has been formed to market in Great Britain electrical control gear manufactured by Klockner Moeller, Bonn. The company's present offices are at 4 Queen Street, Mayfair, London, W.1, and Prince's Buildings, 28 Oxford Street, Manchester. The new managing director of the company is Mr. H. M. Passer.

Dallow Lambert & Co Ltd. have recently moved into a completely new, modern factory situated at Thurmaston, Leicester. The company specialise in the manufacture of industrial dust-control equipment.

The B.P. Group's sales of crude oil and refined products in 1956 totalled 53,000,000 tons—11% higher than in 1955. This was announced by B.P. last week, together with the main profit figures for 1956.

A new office building, costing £300,00, to house all the 300 administrative personnel at Shell Haven refinery, Essex, has recently been completed. This additional accommodation has become necessary owing to the construction programmes now under way. These consist of the expansion of the oil-refining facilities at a cost of over £6½ million and the current development of chemical manufacturing, particularly in the field of nitrogen chemistry, at a cost of a further £6½ million.

Durham Raw Materials Ltd. have been appointed selling agents for the clays produced by Watts, Blake, Bearne & Co. Ltd., of Newton Abbot, Devon. This agency extends to all industries other than the ceramic and refractory trades. The agreement has the effect of combining the technical resources of the two companies.

The Ministry of Education is arranging, in conjunction with the Work Study School, Cranfield, a refresher course on work study for technical college teachers, to be held from July 22, until July 26. Further particulars can be obtained from Mr. C. R. English, H.M.I., at the Ministry of Education.

Pye are reported to be designing and supplying all the equipment for a laboratory for the U.K. Atomic Energy Authority at Dounreay.

Meetings of the Month

The Physical Society

June 4. *Annual General Meeting and Presidential Address:* At the Lecture Theatre of the Science Museum, Exhibition Road, London, S.W.7. 4.45 p.m. The Presidential Address will be given by Professor N. F. Mott, who will speak on "The Physics and Chemistry of Metals".

Society of Chemical Industry

June 11. *Chemical Engineering Group:* At 14 Belgrave Square, London, S.W.1. 5.30 p.m. "Granulation", by W. C. Peck.

The Society of Instrument Technology

May 28. *Annual General Meeting:* At Manson House, Portland Place, London, W.1. 6 p.m. The Bowen Prize Medal will be presented to Sir Harold Hartley, who will become the Society's new President in succession to Mr. A. J. Young, who has held the office for the past three years and who retires after the Annual General Meeting.

Forthcoming Events

Home

May 20. *The Institution of Professional Civil Servants' Annual Delegate Meeting:* At the Winter Garden, Eastbourne, Sussex, until May 22.

May 21. *Oil and Colour Chemists' Association Biennial Conference on "Catalytic Processes Relating to the Surface Coating Industries":* At the Palace Hotel, Torquay, until May 25.

May 28. *The Institution of Chemical Engineers in association with Het Koninklijk Instituut van Ingenieurs (Chemical Engineering Group), De Koninklijke Nederlandse Chemische Vereniging (Section for Chemical Technology), and the Society of Chemical Industry, a Symposium on "The Scaling-up of Chemical Plant Processes":* At Church House, Great Smith Street, London, S.W.1, until May 29.

May 31. *National Industrial Safety Conference:* At Scarborough, Yorks, until June 2.

June 14. *Safety and Factory Equipment Exhibition:* At Bingley Hall, Birmingham, until June 21.

June 17. *The Ninth British Electrical Power Convention:* At the Winter Garden, Eastbourne, Sussex, until June 21.

June 17. *British Commonwealth Welding Conference:* At 54 Princess Gate, Kensington, London, until June 29.

June 17. *Businesss Efficiency Exhibition:* At Grand Hall, Olympia, London, until June 27.

Overseas

May 18. *The Fortieth Swedish Industries Fair:* At Gothenburg, Sweden, until May 20.

May 25. *The Forty-seventh International Trade Fair:* At Paris, France, until June 10.

May 29. *The Institute of Petroleum's Summer meeting:* At the Grand Hotel, Folkestone. "The Influence of Engineering Progress on the Oil Industry."

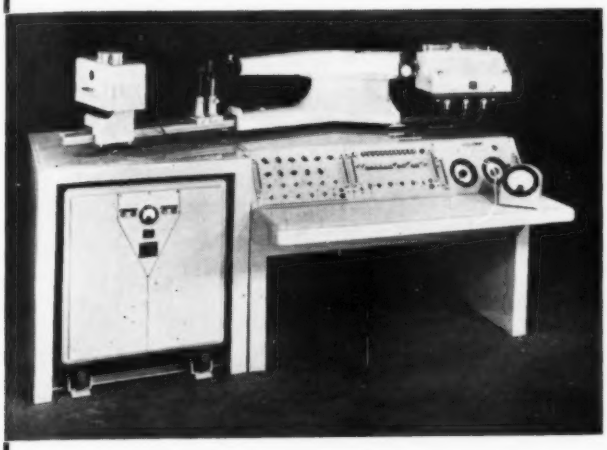
June 1. *Third Scientific Film Festival:* At Turin, Italy, until June 9.

June 5. *World Power Conference, Sectional Meeting:* At Belgrade, Yugoslavia, until June 10.

June 15. *International Atomic Exhibition:* At Amsterdam, Holland, until September 18.

June 16. *The Thirty-sixth International Trade Fair:* At Bordeaux, France, until July 1.

Direct-reading analysis



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